Design for the National Airspace Utilization System Summary of First Edition

Federal Aviation Agency Systems Research & Development Service

September 1962



FOREWORD

Airspace is an important resource and its proper or improper utilization will have a profound effect upon the future welfare of the United States. The use of airspace will have an impact not only on transportation, public safety, economics and military posture, but also on the public's convenience and pleasure.

It was in recognition of this that the Federal Aviation Agency was directed by the President of the United States in 1961 to-

"... conduct a scientific, engineering review of our Aviation facilities and related research and development and to prepare a practicable long-range plan to insure efficient and safe control of all air traffic within the United States. This plan must provide for an orderly and economic evolution of the present system of air traffic control in pace with continuing advances in technology and national needs."

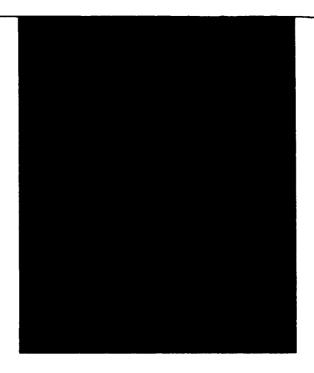
The resultant Project Beacon Report completed in October 1961 and approved by the President November 7, 1961, provided the scientific, engineering review and guidelines for the practicable long-range plan.

Accordingly, a System Design Team was formed within the Systems Research and Development Service of the Federal Aviation Agency to carry forward the guidelines of the Project Beacon Report into a detailed and comprehensive system plan.

On June 30, 1962, the first edition of this long-range plan for the National Airspace Utilization System was completed. Because the problems are complex and extensive, the plan itself is voluminous and the details on which it is based are highly technical. Yet it is important that the essence of this plan be understood by many people who cannot afford the time to study the details of the plan.

This summary describes all essential elements of the plan. Full descriptions are given in the unabridged master plan: the first edition of the *Design for the National Airspace Utilization System*.

The system design and plan for the National Airspace Utilization System must grow and evolve with changing conditions and with new technology. Subsequent editions will be issued periodically to incorporate improvements to the viable design.



This report presents a system design for the safe and efficient movement of air vehicles in the Nation's airspace. This design must be responsive to our national aviation goals and objectives. It must also be capable of timely and orderly implementation within the limitations and constraints of the practical and physical world in which we live.

The system is not simple nor can it be entirely defined in the precise diagramatic script of the system engineer because the problem is complex, diverse and comprehensive. The navigation chart, rule book, airplane, digital computer and controller are typical elements of this system.

In discussing such a system, where the elements are heterogeneous in nature, it has been found convenient to divide the system into a logical set of 10 basic components. All of these must be woven together in any airspace utilization system. Any system which provides for the movement of air vehicles must consider these 10 basic components because they all interact so intimately that none can be omitted without some loss in system integrity in any feasible and

reasonably effective airspace utilization system. These components are :

 Vehicle Pilot Airport 	Essential to manned flight.
4. Navigation5. Aeronautical Information6. Weather Information	Permitting air travel and contributing to safety.
7. Rules and Procedures	Permitting multiple vehi- cles to share airspace and facilities.
8. Communications9. Ground Controller10. Air Traffic Control	Permitting safe, orderly flow of traffic and all-weather flying.

While the complete system design weaves together all 10 basic components, this brief summary places major emphasis on a description of the air traffic control subsystem. At the present time, the interest of the aviation community is particularly focused on this subsystem because it involves the greatest development of equipment and expenditure of funds.

The first section of this summary defines the problem. It describes the goals and objectives, the limitations and constraints; it gives the dimensions of the air traffic situation in terms of density distribution, flow patterns, altitude and speed. This section also describes the type of services FM is providing or will provide without describing the means or wherewithal.

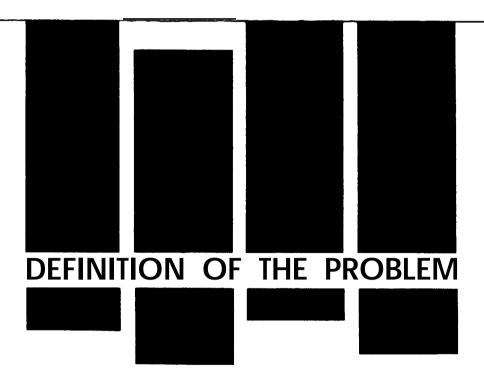
The second section outlines the environment and the devices that can be modified, rearranged or evolved into the air traffic control (ATC) subsystem.

The third section describes the significant design principles and equipment techniques applied to the ATC subsystem design problem.

The fourth section describes the air traffic control functions and related data processing and display equipment.

The fifth section contains a brief operational summary indicating how a flight will be handled in the system.

The final section presents a time schedule for the progressive development and implementation of new equipment.



Goals

Responsibility for the safe and efficient utilization of the Nation's airspace by both civil and military aircraft was placed on the Federal Aviation Agency by the Act of 1958. The words of the Act have been used to establish FAA goals for system operation. In essence, the Act defines overall Agency responsibilities and provides the legal basis for carrying them out. Detailed technical solutions to problems are not found in these words. However, every part of the solution must be measured against the words of the Act and their interpretation.

The need to achieve a satisfactory level of safety is a paramount goal toward which FAA policies and procedures are directed. The Congress, which established FAA in 1968, has the ultimate responsibility in this area. The achievement of this goal, however, cannot be realized without the cooperation of all user groups.

The system design provides for freedom of transit of the Nation's airspace with minimum interference with the intent of the pilot. The requirement for safety while in transit. in the airspace leads to the need for spatial segregation between controlled and uncontrolled aircraft by

designation of airspace since it is not feasible to provide separation service for all aircraft. It is recognized that in some airspace the complete segregation of controlled and uncontrolled aircraft may not be achieved.

The desires for airspace use as well as the types of operations of all users, both civil and military, have been considered in the design of a single common system. In addition, it is recognized that the system must be capable of operating under both peacetime and wartime conditions. For this reason, the system design considers the need to support certain specific military operations in addition to those services that are provided for routine civil-military use of airspace. Another FAA goal is to provide the required services at minimum cost to the Nation. In support of a design with a cost/benefit orientation, this goal requires that consideration be given to the use of facilities which have been established by other branches of the Government. A particular case in point is the joint use of civil and military radars for ground-based data acquisition.

Constraints

The goals that have been established by interpretation of the Act of 1958 can be realistic only if they take into account certain constraints necessarily imposed on any practical real-life system. The attempt here is not to design a "perfect" system but rather to design one that is practicable, taking into account aviation's place in the national economy, the public's desire for safety and the airspace users' desires. Although aviation represents more than 50 percent of the total common carrier market, this is only a small per-

centage of the total transportation activities of the American people. Furthermore, the contribution of the aviation industry to the Nation's economy represents approximately two percent of the gross national product. These figures are expected to remain essentially constant over the next 10 years. It may be assumed, therefore, that the level of financial resources available to the FAA will not change significantly. Consideration of the use of available techniques for an airspace utilization system must be tempered by recognition of aviation's role in the economy.

The system must take account of the range of pilot capability that exists today and the recognition that it will not change appreciably during the next 10 or 15 years. The system must also recognize the types of aircraft and their equipment which now exist and which will be changed only gradually during this same time period. In addition to constraints imposed by aircraft and pilot capabilities, the system design must also consider the constraints imposed by existing state-of-the-art in technology.

Today's air traffic control subsystem represents an establishment valued at approximately \$1 billion. A large portion of this investment is in electronic equipment procured since 1956. There are many years of useful operational service in these facilities and any contemplated replacement program would need justification in terms of superior service coupled with a subsequent reduction in operating cost. In general, much of what exists now will be used for many years to come and the introduction of new system components will be in the nature of additions rather than substitutions.

The diversity of aviation user requirements and desires in the United States is of such magnitude that it may be looked upon as a design constraint because it requires an approach geared to diversity in operations and economics. Many solutions that have purely technical superiority must be rejected when analyzed in the light of this constraint.

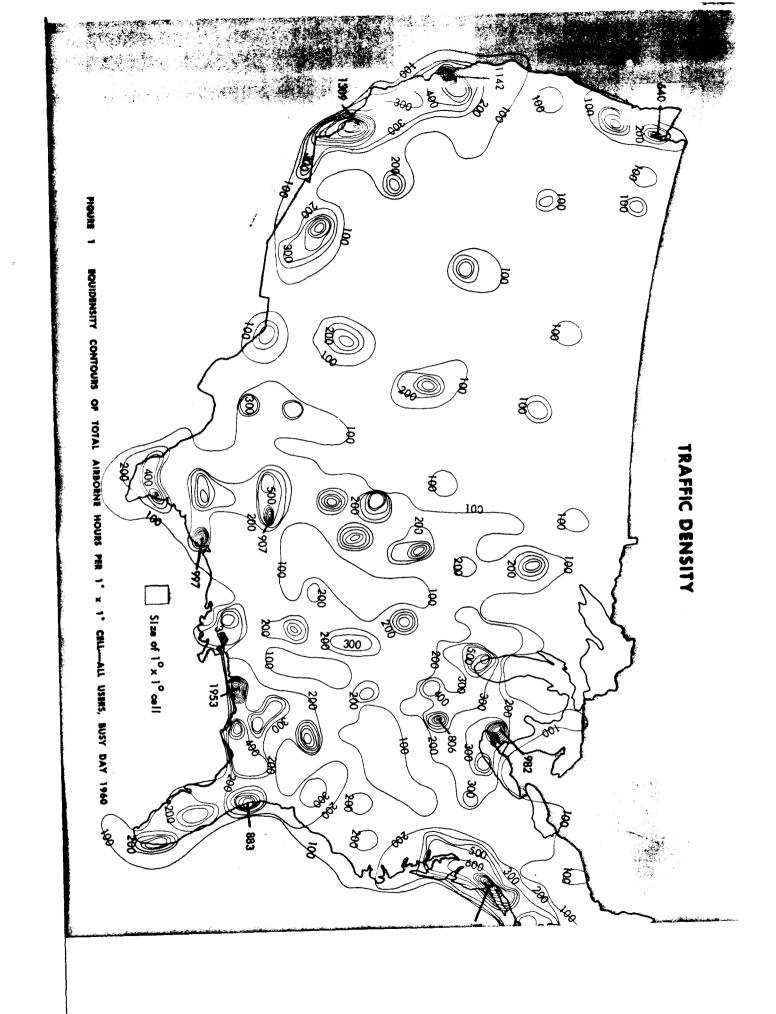
The attempt in this design is to create a "best" system commensurate with practical economics and full recognition of -all other factors. For example, VORTAC was selected as the airborne navigation technique, not because it is the best possible navigation subsystem that could be imagined, but rather because it can do the job and is in an advanced state of implementation on the ground and in aircraft. When economics, availability and technical considerations are weighed, VORTAC has no competitors for the next decade at least. This same method of analysis has been applied to other specific selections of techniques to provide ATC service.

Consideration of the factors indicated above places considerable emphasis on the need for an evolutionary approach to almost all aspects of system change and may require a compromise with the best technical solution. Ingenuity is needed to evolve the best methods for system advancement while minimizing the impact of obsolescence and the economic burden associated with change. Although it is possible and necessary to design in this manner, this requirement places a decided constraint on freedom of choice.

The decision to design a system to provide a common civilmilitary ATC service requires consideration of additional factors. In this usage, ATC service implies support to military operations, such as scramble and recovery of interceptors, flight following of SAC aircraft, provision for radar bomb-navigation training, provision for rendezvous and refueling and military training area operations. It does not include the capability of the system to detect hostile aircraft or to control weapons. It will provide limited protection against damage, sabotage and ECM. It will track known aircraft. and can supply military organizations with continuously updated information on such flights. The design, will permit the control of known cooperative aircraft in the national airspace as may be dictated by military authority in times of national emergency.

The system design is not constrained either to make use of SAGE Centers or to rule out their use. The design decision is that use of SAGE Direction Centers and their internal equipment is not a "best" solution under the ground rules of economic practicability, geographic location and technical state-of-the-art.

The system design presented here for the ATC subsystem can be progressively improved by the evolutionary addition of new equipment over a period of time. It can take advantage of advances in state-of-the-art and will satisfy the operational requirements at least through 1975 and probably beyond.



The Traffic Picture

An "ideal" system might provide a uniform grade of service throughout the airspace over the entire United States at all altitudes. This system design recognizes that such a concept is not economically feasible nor necessary for the safe and efficient use of all airspace. The ATC facilities and services will be tailored to the needs created by local traffic densities, traffic flow, aircraft type and mode of operation.

The density of aircraft over the United States is shown as a contour plot of airborne hours in Figure 1. Several significant system design considerations can be noted:

Traffic density corresponds geographically to population centers except in a few military training areas.

The high density traffic areas are located mainly along the coastal boundaries of the United States.

The range of densities by one degree cells (latitude-longitude) is large. The cells containing Pensacola, Los Angeles, New York and San Francisco have over 1,000 hours of aircraft flying time per day. Only 30 other cells have over 500 aircraft airborne hours per day, and the large majority of the cells have less than 100.

The mix of traffic by user group varies considerably among the cells. The three highest density areas and their percentages of total operations by user groups are given below.

Air Carrie (perce	r Military nt) (Percent)	General Aviation (Percent)
Pensacola 1	96	3
Los Angeles 2	49	49
New York 17	20	63

Census data indicate that the greater the population of an area the greater its predicted population growth. Thus the areas with the larger number of airborne hours today will probably be the areas that will exhibit the greater increases in activity during the next 15 years. The only abrupt changes possible would result from relocation of military flight activity centers. Since concentration of general aviation aircraft follows the pattern of population distribution and associated air carrier activity, the critical airport problems stemming from density and mix of aircraft arise at relatively few locations in the U.S.

The contours of airborne activity are for a 24-hour day. Instantaneous traffic density, however, has a regular and predictable diurnal variation. There is about eight times as much instantaneous activity in the conterminous United States between noon and 4 p.m. as there is between midnight and 6 a.m. (Eastern Standard Time). This pattern, which is not expected to change, requires consideration in maintenance scheduling, appropriate manning and designation of equipment off-line periods.

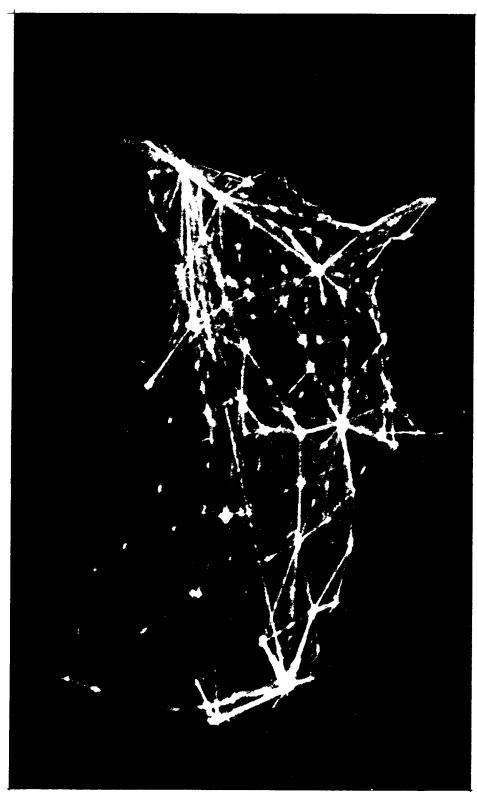


FIGURE 2 TOTAL ITINERANT AIR TRAFFIC FLOW-BUSY DAY 1961

Traffic Flow

The air traffic analysis for system design must include traffic flow as well as density. A flow pattern for all itinerant flights in the United States is shown in Figure 2. The plot was made by photographing a cathode ray tube on which each flight was indicated by a straight line between its origin and its destination. This figure shows all itinerant flights at all altitudes. Such plots have also been made by user category and altitude band.

A difference in the flow organization may be noted between the eastern and western portions of the United States. West of the Mississippi, the natural flow is generally along well defined routes, while in the East the traffic is more widely distributed in direction and less confined to a small number of natural routes. Examination of the distribution of flight lengths shows that the vast majority of flights cover less than 500 miles. Flow patterns for the shorter flights are radial in nature and are associated with several widely scattered high density terminal areas connecting these to a large number of lesser terminals. When this flow pattern is broken down by altitude bands, analysis shows that between 8,000 feet and 24,000 feet the traffic is more concentrated along natural routes than it is either above or below this band.

Studies have indicated that civil terminal area activity is generally proportional to the population of the area. Considering traffic flow, these studies have also indicated that the number of enplaned passengers travelling between two communities is generally proportional to the product of their populations divided by the distance between the two areas. These relationships permit forecasts of traffic flow based on population forecasts.

The traffic flows of various user groups are quite different. Air carrier flights are predominantly itinerant and along the airways. About one-third of all general aviation activity is local flying; the other two-thirds is itinerant, partially along the airway structure (about 20 to 30 percent). Flight activity and flow of both air carrier and general aviation aircraft are functions of the population distribution. As much as two-thirds of the military flying is local flying at or near a number of busy military airports. More than one-third of this local military flying is in reserved airspace. Military itinerant flying has two types of patterns. Administrative flights form a crescent of flow from the east coast across the Southern States and up the west coast. Tactical flights tend to concentrate in the central United States. Military tactical flying is conducted largely on an area rather than an airway basis.

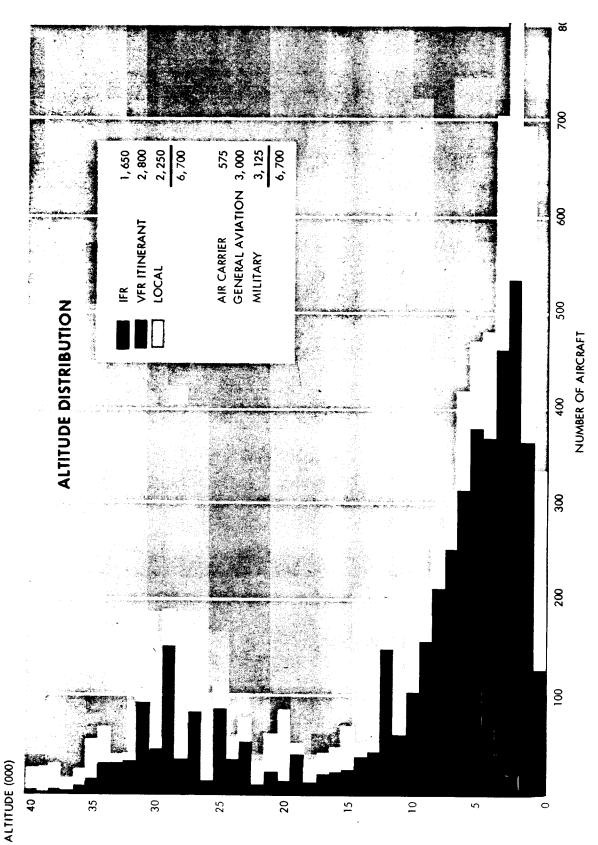


FIGURE 3 FORECAST AVERAGE NUMBER OF AIRBORNE AIRCRAFT-PEAK HOUR, FRIDAY, AUGUST 1962

Altitude Distribution of Traffic

While population largely determines the geographic distribution of traffic, the altitude distribution is largely dependent upon the characteristics of the air fleet, the distribution of flight lengths and the terrain of various areas. A typical instantaneous altitude distribution for the United States is shown in Figure 3. The most significant system design factor to be noted is that the bulk of traffic operates between 2,000 feet and 8,000 feet.. Data for 1961 were used in preparing this plot. Forecasts indicate that even more traffic will be concentrated in this band in the future.

The forecasts through 1975 indicate a slight decrease in the overall jet fleet and a small increase in the turboprop fleet. The large increase in numbers of aircraft will be in the piston fixed-wing group. These aircraft will spend most of their airborne hours below 8,000 feet and will have a higher average velocity along with a wider range of velocities. Further, it is in the 5,000- to 10,000- foot region that forward visibility is most likely to be less than 5 miles.

The altitude distributions of the various user groups differ. The most-used air carrier altitudes are between 4,000 and 20,000 feet above terrain. The greatest density, however, is between 4,000 and 10,000 feet. The most-used general aviation altitudes are from 2,000 to 7,000 feet above terrain. The military operate in three distinct altitude bands. These include a large number of helicopter flights under 3,000 feet, with the remainder of the military activity concentrated between 2,000 and 11,000 feet and above 24,000 feet. It is between 3,000 and 8,000 feet that there is the greatest mix of traffic by user group.

The flow patterns show that the volume of air space located east of a line running generally through Minneapolis and Kansas City including all altitudes between 3,000 and 8,000 feet have the greatest diversity in the location and direction of traffic flows as well as the most traffic. Traffic above 24,000 feet also has a great diversity in location and direction, but the traffic is much less dense and has a narrower speed distribution.

Terrain has a significant effect on the altitude distribution of traffic. Over the mountainous area of the West, traffic is more uniformly distributed by altitude although still peaking at several thousand feet above terrain.

The forecast traffic picture is one of increasing traffic density at growing and already large centers of population and of greater concentration in an altitude band 5,000 feet thick beginning 3,000 feet above the terrain. This region has not only the greatest number of aircraft, the widest range of aircraft speed, the poorest forward visibility and a mixture of climbing and descending as well as straight and level flying, but also the greatest variety of airborne equipment.

The pilot's ability to maintain "see and avoid" separation is reduced by the following factors: high density of aircraft, greater speed and speed distribution, lower visibility, greater mix of types of flying and higher altitudes. In the region between 3,000 and 8,000 feet, all of these factors except higher altitudes have the most critical effect.

The best way to minimize the effect of these factors is to establish positive control airspace. Positive control cannot

be applied in all airspace in which ground-based control service is provided because: (1) the conditions requiring its use are not present to a degree which justifies the cost in all such airspace and (2) the requirements that must be placed on aircraft owners and pilots will not be completely met by 1975. This system design, therefore, will permit the establishment of positive control in airspace portions (area, airway and terminal) where specified criteria can be met. In other controlled airspace, the system will provide ground-based separation service to more flights includ-

ing non-IFR pilots and aircraft. In addition, speed limits and/or traffic advisory information will be required in certain airspace.

Thus the system design will provide a capability for positive control in some major terminal areas and for positive control airways where they are needed. During the next 10 years the problem of mixed controlled and uncontrolled aircraft will not be eliminated in most airspace below 8.000 feet.

FAA Services

The accomplishment of safe and efficient movement of vehicles in the system is achieved by providing various services the users of the airspace. Uniform service in all airspace would be desirable, but practical considerations make this goal unrealistic. Nigher grades of service will be provided where the need is greater as determined from traffic density and distribution.

The basic operational services provided to pilots include:

Air Traffic Rules. The rules governing the flight of aircraft serve the pilot by allowing him to anticipate the actions of others. Where control service is provided, rules offer a better means for the ground-based system to predict the future actions of the pilot.

Ground-Bused Navigation Facilities. Navigation facilities provide the pilot with accurate guidance and establish a common system of reference for the pilot and the controller.

Aviation Weather Information. Current and forecast meteorologic information is required for preflight planning. Pilots in flight need current meteorologic data to continue flight in a safe and efficient manner.

Flight Planning and Inflight Information. Through flight service stations, Notices to Airmen and regular publications, the pilot is aided in selecting routes and airports most suitable for the safe and effective performance of his flight. While in flight, pilots receive timely notification of hazardous weather and significant status reports on navigation facilities and airports.

Search and Rescue Alerting. The filing of a flight plan and subsequent followup action afford a means for assuring that search and rescue services will be alerted whenever a flight is overdue.

Air Traffic Control. The ground-based ATC subsystem offers increased safety by keeping controlled aircraft separated from each other and from hazardous areas.

Of the types of services just described, four are common to all airspace: (1) air traffic rules, (2) aviation weather information, (3) flight planning information and (4) search and rescue alerting. The ready availability of the latter three of these services will depend upon the communications resources at the disposal of the FAA. Weather and flight planning information will be more readily available and contain more fine grain detail in areas of high aviation activity.

Ground-based navigation facilities provided by the Government will include both radio and visual equipment. VORTAC radio navaids will radiate signals maintained to a known standard of quality in all controlled airspace below 60,000 feet. Coverage will be limited in uncontrolled airspace to the spill-over from service in controlled airspace. Airports meeting established criteria will have electronic and visual aids for approach and landing.

Pilots in flight will be notified of hazardous weather and the status of navigation facilities and airports as appropriate. Noncritical weather and status information will be broadcast or furnished on request,. These services will be available within communications range of the flight service stations and air traffic control facilities involved. In the vicinity of airports without control towers but having flight. service stations, traffic information will be given to pilots of aircraft equipped with two-way radio.

Air traffic control service will be furnished by FAA wherever traffic conditions justify the establishment of controlled airspace. The grade of service will range from positive separation of all aircraft in certain areas using ground-based radar to limited separation in nonradar airport traffic areas using visual observation.

Area positive control service will be provided throughout the conterminous United States at the higher altitudes. A limited number of "high activity airways" with positive control segments will connect the few hubs of dense aviation activity where terminal area positive control service will prevail. This service will be provided below 24,000 feet to flights without instrument capability as well as to those with it.

Pilots receiving positive control service are assured by the ground-based ATC subsystem of traffic separation from all other aircraft in designated areas. The only exceptions to this are (1) within temporary blocks of airspace set aside for aircraft to perform special maneuvers not compatible with normal control techniques and (2) in the final ap-

roach area of terminals where some pilots will be requested to maintain their own separation from aircraft they are following.

Nonpositive control service will be furnished in conventional controlled airspace to all IFR flights and to VFR pilots if they request it. In the enroute environment and in terminal radar environments such VFR flights will be afforded separation from other controlled flights by control techniques similar to those used with IFR flights. Both IFR and VFR pilots, however, will be required to see and avoid uncontrolled VFR flights.

Controlled airspace other than positive control will be organized principally on an airway basis. The air traffic control subsystem, nevertheless, mill have a capability for controlling on an area basis, allowing pilots to choose routes according to the type of operation involved. The extent of controlled airspace and the type of service provided-radar or nonradar-will depend upon traffic activity. Nonradar control service will predominate in areas of low traffic activity. Radar service will be furnished in all other controlled airspace. In areas of high traffic adivity, multiple primary radar and/or radar beacon coverage will minimize the need for return to nonradar operations as a result of equipment outage.



Having described the FAA's goals in providing a National Airspace Utilization System, the constraints necessary in a practical world and the air traffic services that the FAA will provide to satisfy its responsibilities, it is necessary to describe the environment within which the air traffic control subsystem will operate. This environment may be considered as made up of airspace with its appropriate subdivisions, airports, a weather subsystem and a large number of facilities, such as centers, towers, IFR rooms, flight service stations, radars, and the like. All of these are tied *together with a communications network. Description of this total system environment is essential to assist in understanding the requirements for the data processing and display portions of the ATC subsystem.

Airspace

Enroute controlled airspace will be divided into positive control areas, control areas, airways and high activity airways. High activity airways will contain positive control and nonpositive control airway segments. Each specific airspace configuration will be designated according to criteria that will be based on traffic density and speed distributions.

The base of the upper positive control area overlying the conterminous United States will be in the order of 14,500 feet east of the Rocky Mountains and somewhat higher over them. Positive control airway segments and positive control terminal corridors will link this airspace to positive control terminal areas.

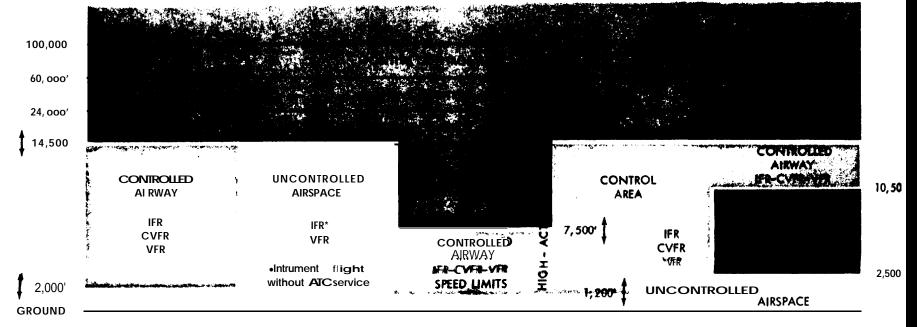


FIGURE 4 REPRESENTATIVE ENROUTE AIRSPACE CONFIGURATION

Above 24,000 feet in the positive control area, only IFR operations will be permitted. In other positive control areas and airway segments, the system will provide for both IFR and controlled visual rules (CVR) operation. In the remaining controlled airspace (control area and airways) another class of flight, controlled visual flight rules (CVFR), will be added to the existing IFR and VFR operation, enabling VFR pilots to receive control service in the enroute environment.

At the busier terminals, the arrival airspace structure will permit transition from two to three terminal entry points via VOR routes with at least two turning points between each terminal entry point and the final approach course. Each transition route structure will utilize- two or three radials for flight path adjustment. Although flights will usually be controlled by assignment of appropriate VOR routes for navigation by the pilot, traffic will be monitored with radar. Low performance aircraft entering the terminal via routes feeding the arrival terminal entry points will use the same routes as high performance aircraft, but will be segregated from those aircraft by virtue of their operation at lower altitudes.

Routes will be set up to serve at least two arrival paths to the airport to allow for operation with different wind conditions. The routes not in use for arrivals at a particular time will serve as departure routes for high performance aircraft climbing to enter the upper positive control area.

Wherever a terminal positive control area is designated,

the airspace structure from the terminal entry points to the airport will contain stepped corridors of positive control airspace centered on the route structure previously described. In the immediate vicinity of the principal airport, positive control airspace will be designated on an area basis to a distance of 15 to 25 miles from the airport. At this distance the area type positive control airspace will end, giving way to the stepped corridors as depicted in Figure 5. Within about 5 miles of the airport, the positive control airspace will go down to the surface. Beyond, the base will be 700 feet above the surface, stepped upward at greater distances.

CVR operations will not be required to enter via the VOR routings from the terminal entry points in terminal positive control airspace. The 700-foot or higher base of the ter-

minal positive control area will allow for flights to and from smaller airports in the vicinity without entering positive control airspace. To the extent possible, VFR airspace will be cut out of the 5-mile radius positive control zone surrounding the principal airport to allow uncontrolled operations at smaller airports inside that radius.

At nonpositive control terminals with radar capability, an "airport traffic communications area" will be established within which radar control service will be furnished to all flights arriving and departing the airport served by the terminal radar facility and to all other flights requesting it. This will be IFR and CVFR service. Since not all traffic in the area will be controlled, pilots will be required to 'see and avoid" other aircraft.

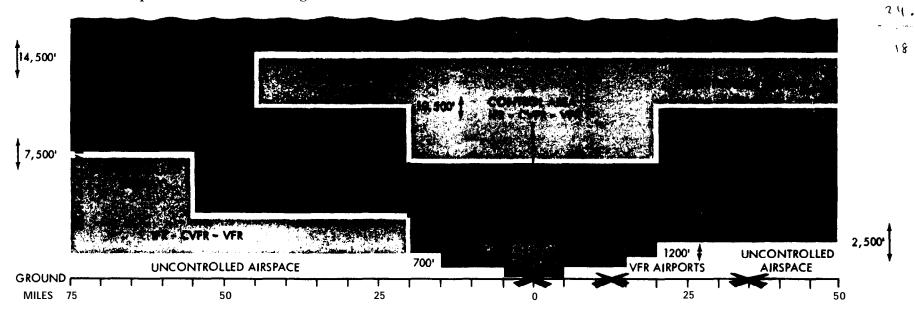


FIGURE 5 REPRESENTATIVE POSITIVE CONTROL TERMINAL AREA

AIRSPACE CATEGORY	TYPE OF SERVICE & SEPARATION	SYSTEM ELEMENTS INVOLVED		
Minimutalitud priphardens)	Information only All electric uncon-	Nevigation and commutation (as eveilable)		
See activity str- us, (stratelled shapes)	Separation between all PR & CVFR Alterest Uncentralised atrensts allowed	Nevigation and communication Limited primary reder Limited reder beacon		
Medium activity alreay and Mgh activity air- may (nanpositive acrital sigmant)	Separation between off IFR & CVFR etrerali: Uncontrolled atterali allowed	Nevigation and communication Primary rader Reder Recom (not all aircraft transponder aquipped)		
High activity already (positive central segment)	Separation between all IPR & CVR alresoft No attor Hight allewed	Nevigation and communication Primary Roder Roder Boocen		
Area positive control (APC)	Before FL 240. Separation between all IFR & CVR. No other flight allowed Above FL 240. Separation between IFR. No other flight allowed	Nevigetien and communication Primary rader Rader Beacon		
Special A K (above FL-600)	IFR only	Communication Others to be determined.		
FIGURE 6	LEVELS OF SERVICE, ENROU	ITE AIRSPACE		

Levels of ATC Service

This table indicates the correspondence of airspace category, type of separation service and the ATC subsystem elements required in enroute airspace to provide a level of service according to the system need. A basic design principle is also reflected which requires that the degree of ground-based separation service be dictated by density, flow, speed and mix of traffic.

Aircraft operating in uncontrolled ("elsewhere") airspace are not provided ATC separation service. Navigational guidance is available in uncontrolled airspace only as a byproduct of the subsystem designed to serve controlled airspace.

The next category is the low and medium activity airway. Navigation and communications services are available for all operations. Only controlled aircraft are separated by ATC.

As traffic activity becomes greater, more and more dependence will be placed upon use of radar traffic control techniques. Increased movement rates will result from the integrated display of radar and nonradar data.

The highest grade of service is provided by the designation of positive control airspace. This pertains to either areas or segments of high activity airways. Since only controlled aircraft are permitted to operate within these portions of airspace and since transponder equipment will be used, the ground-based ATC subsystem will offer the highest level of safety and service.

SERVICE AREA COMM.NAVIGA			TION RADAR BEACON					
			VHI			DME (ODED IDENT.	ALT.
POSITIVE CO	NTRO	L						
a	bove bove elow	60,000 IFR 24,000 24,000	IFR IFR CVR	X X X	ta X X X	e determ X X X	ined X X X	× × ×
B. Airways b	elow	14,500	IFR CVR	X X	X X	X or 2 VORs 0*	x x	x x
C. Terminal /	Areas		IFR CVR	X X	X 0	X 0	0	X*
D. Control Zo	nes		IFR CVR	X X	X 0	X 0	0 0	X* X*
CONTROLLE (Non-Positive		SPACE						
A. Routes/Are	eas		IFR	X	Χ	Xor 2 VORs	OG	OG
			CVFR VFR	X 0	χ O	0 0	OG 0	OG 0
B. Terminal A	Areas		IFR CVFR VFR	X X 0	X 0 0	X 0 0	0 0 0	000
c. control z	ones	IFR CVF VFI	R X		X 0 0	X 0 0	0 0 0	0 0

FIGURE 7 AIRBORNE EQUIPMENT REQUIREMENTS

... X =Required by System Design 0 = Not Required by System Design

Airborne Equipment Requirements

Figure 7 indicates the airborne equipment needed as a function of airspace in accordance with the design. The chart outlines the equipment required to achieve optimum utilization of the airspace by different classes of flight but is not a statement of mandatory requirements. System integrity will be maintained by assuring a uniform performance level for those characteristics that affect system operation, regardless of the aircraft type in which the equipment is installed. There is no attempt to depict degrees of performance quality which may exist for other factors since this is a regulatory matter based on the level of safety associated with different types of flight operations.

In area positive control airspace and on positive control airways the transponder will be required. In other airspace the installation and use of transponders is recommended and may be required in some special use airspace.

Two VOR receivers may be used in lieu of DME enroute. However, DME is indicated for use in terminal areas s0 that the system will no longer be dependent upon LF aids.

This chart does not cover all airborne equipment required by the system. For example, there is no mention of altimeters, navigation or attitude instruments, even though they are integral parts of the system.

The notation X* will change to X if SLATE is implemented. OG will revert to 0 if both primary radar and radar beacon continue in use for enroute control. OG will become X if a "transponder only" enroute system is adopted. 0* violates good system design and will increase the system workload somewhat.

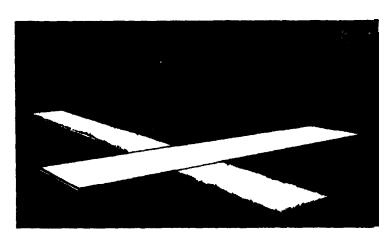


FIGURE 8 CATEGORY | AIRPORTS

Airports

Examination of airport activity and facilities reveals that airports can be grouped into five categories. Figures 8, 9 and 10 show the physical facilities generally anticipated for each category.

Category I makes up the major percentage of airports within the United States. They will number about 7000 by 1970. There will be no electronic navigation aids provided by the Federal Government specifically to serve these airports.

Category II airports will be provided with IFR capability and control service under Federal auspices, but will not include a control tower at civil fields. Civil airports in this category will number about 400 and military about 60.

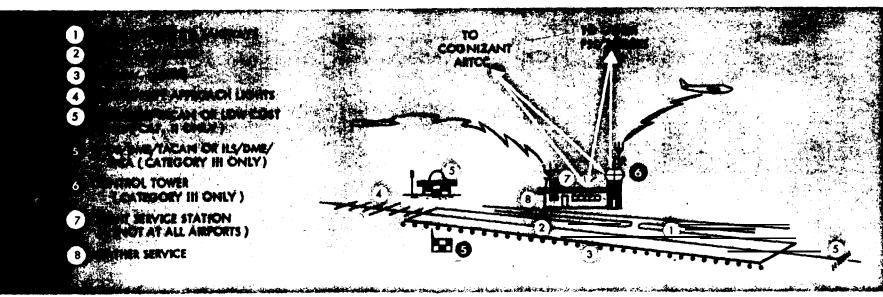


FIGURE 9 CATEGORY II & III AIRPORTS

Category III airports are the first category to have an FM-operated airport traffic control tower. Civil airports in this category will number approximately 250 and will have control zones in all cases. The number of military airfields will be approximately 60 to 75.

Category IV airports are characterized by the introduction of terminal radar traffic control. Radar will be used in the provision of both IFR and VFR air traffic control services. This will introduce the concept of controlled visual flight rules (CVFR). Civil and military airports of this type will number approximately 100 each.

Category V airports are those located within a complex of airports (metroplex) where the concentration and mixture of high and low performance aircraft are such as to require the subdivision of airspace so that all aircraft operate under ATC control. The airspace surrounding one or more major airports in such complex terminal areas will be **designated** positive control. Civil and military terminals of this type are expected to number about 6 to 10 each.

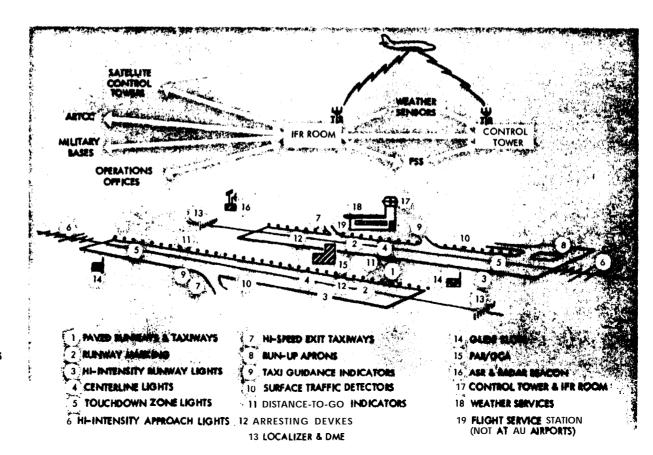
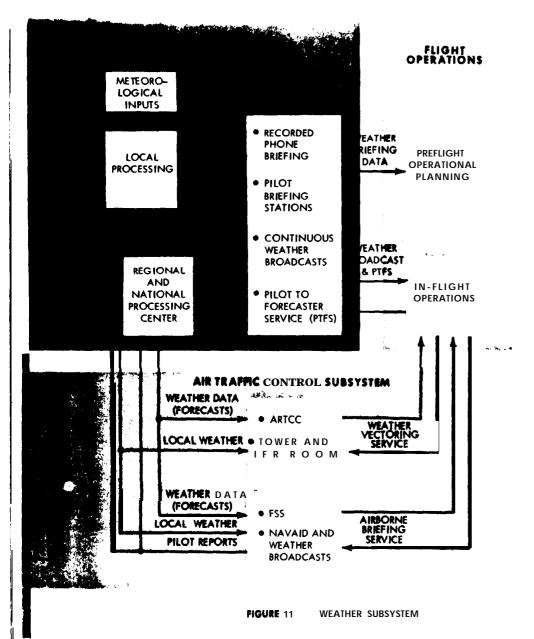


FIGURE 10
CATEGORY IV & V AIRPORTS



Weather Subsystem

To plan flights, pilots need to know present and short-term forecast weather at the departure terminal, longer-term forecasts of enroute and destination terminal weather and winds aloft information for the time period of the flight. Preflight planning information will be available at pilot briefing stations and through telephone links to the briefing stations. Present plans include implementation of up to 750 pilot briefing stations in the United States. Each station will have the latest operational weather data available for display to the user. Information for preflight planning in remote areas will be obtained through automatic and manual telephone briefing.

Enroute pilot briefing will be accomplished by periodic weather broadcasts for routine inform&on, and the pilot-to-forecaster service (PTFS) for special briefings on severe weather conditions. Additional pilot-to-forecaster installations are required for nationwide coverage.

The ATC subsystem requires weather information for terminal control, enroute control and management decisions. Terminal decisions are based on short term forecasts covering relatively small geographic areas. Enroute decisions are affected by longer-term forecasts covering larger geographic areas. Management decisions are concerned with events up to 24 hours or more in advance, covering the continental United States. Weather information for each of these functions will be provided in processed form. Weather information is converted in the data processor to accurate time predictions of flight progress and displays of identified severe weather outlines.

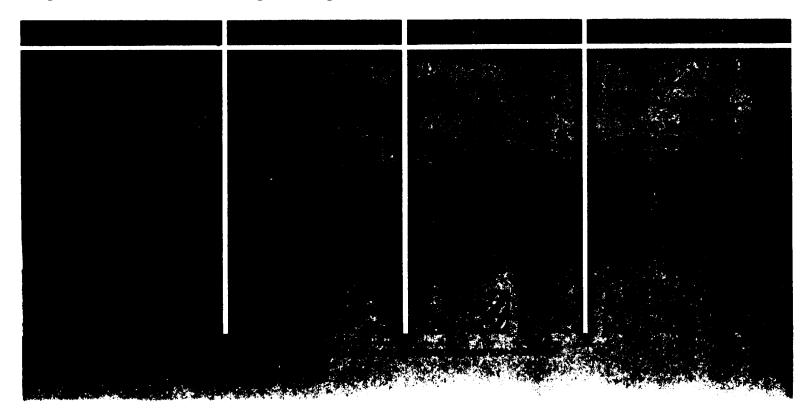
Navigation Subsystem

The system will provide navigation signals in all airspace in which active ground control of aircraft is exercised. A design principle states that navigation service is required even where complete radar coverage exists so that a pilot may independently determine the position of his aircraft. The equipment technique to be used for the enroute, transition, approach and departure phases of flight will be VORTAC. Self-contained aids will be used to a greater extent than at present for enroute operations, especially in positive control areas.

Figure 12 depicts the ground-based and airborne electronic navigation elements to be used 'during different phases of

flight. Doppler navigators used for enroute operations will be referenced to VORTAC facilities. In the transition area, TVORs will be available for let-down. DME will be added to permit improved utilization of the ground facilities. GCA/PAR is shown both in recognition of the military requirement as well as a possible need for monitoring ILS to allow a reduction of operating minima. The use of DME at ILS will lead to the eventual elimination of low frequency aids associated with the ILS.

Future all-weather landings will be achieved by an extension of ILS using a flare-out landing computer. The computer may use either an airborne radio altimeter or a ground-based vertical scanning transmitter as a guidance input.



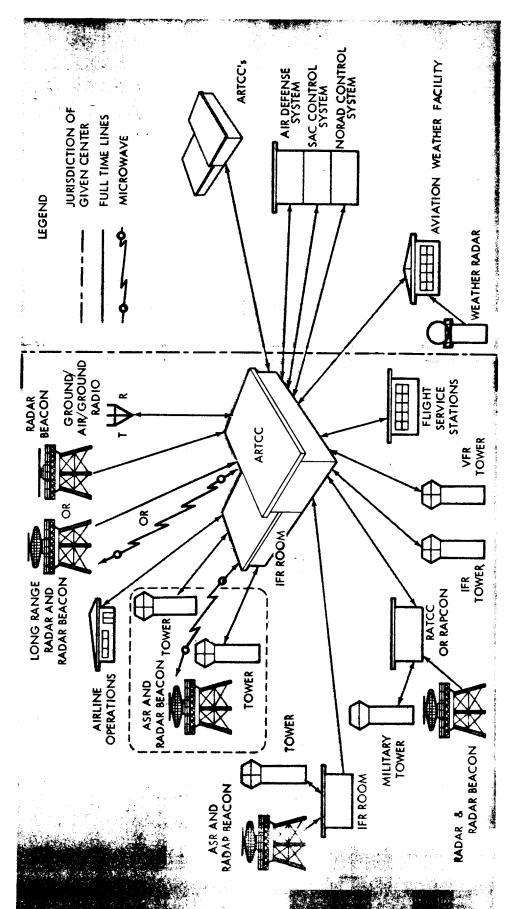


FIGURE 13 TYPICAL AIR TRAFFIC CONTROL ENVIRONMENT

Air Traffic Services Facilities

The air route traffic control center (ARTCC) acts as the hub of the network that serves the IFR, CVR, CVFR and VFR traffic. The flight service station, which is a part of this network, is the primary source of preflight, and inflight service to VFR traffic. Enroute air traffic control service will be provided from air route traffic control centers, each of which has jurisdiction over a unique portion of the United States airspace. The implementation of the system design will make it possible to reduce the required number of air route traffic control centers.

Combined IFR rooms for terminal areas having several high activity airports in close proximity to each other and the center, may be located at the center to make full use of the data processing capability available in the center. Each center will have sufficient radio coverage to encompass controlled airspace within its area. Enroute primary radar and radar beacon data within the center area will be remoted to the centers. Wind data will be sent from the aviation weather subsystem to the ATC processor. Data concerning hazardous weather areas will be transmitted to the air route traffic control centers for presentation on the active control displays.

Aircraft movement information needed for air defense will be automatically forwarded to manual and automated military control centers.

The functions in the domestic airspace presently performed by the central altitude reservation facility (CARF) will be absorbed by the automated enroute centers.

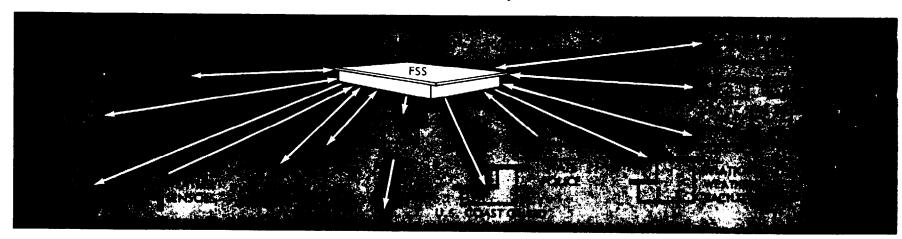


FIGURE 14 TYPICAL FLIGHT SERVICE STATION ENVIRONMENT

Communication Networks

Extension, improvement and new design of communication networks and facilities will be required between now and 1975 to serve the expanding and changing requirements of the ATC subsystem. Figure 15 shows the complexity of the present communication system configuration.

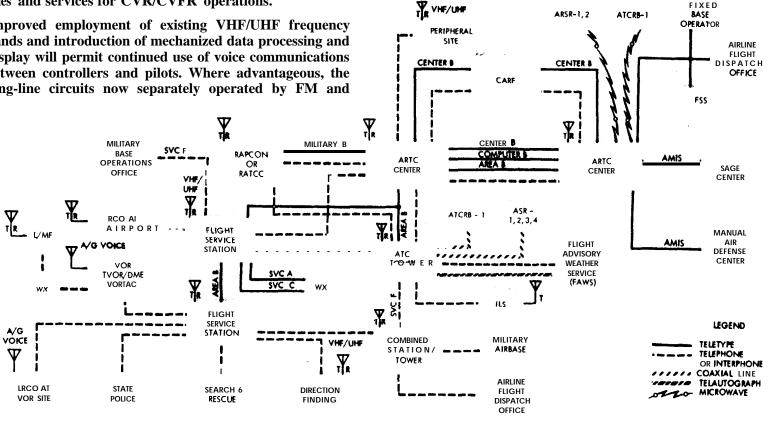
Requirements for extended services include an increase in the number of FAA-operated control towers from 260 to about 350, expansion of pilot-to-forecaster weather advisories and services for CVR/CVFR operations.

Improved employment of existing VHF/UHF frequency bands and introduction of mechanized data processing and display will permit continued use of voice communications between controllers and pilots. Where advantageous, the long-line circuits now separately operated by FM and

the Department, of Defense will be consolidated. Solids state techniques will be utilized to conserve size, power and maintenance costs for such components as amplifiers, radio equipment and switching centers.

Advances in technology, such as improved remoting equipment for radar and beacon data and means for digital data transfer for forwarding control messages between ATC facilities and for flight plan entry, will be utilized.

FIXED



DESIGN CHOICES

The discussion given in the preceding sections presents a general analysis of the problem of airspace utilization and a more specific examination of the ATC environment. This analysis, applied to the airspace over the continental United States and the time period throughout which the system must provide satisfactory service to the Nation, leads to the selection of significant design principles and equipment techniques. Some of these specific choices are decisions which stem from the design process of analysis followed by synthesis. Other choices have not involved a free selection among alternatives, but rather have been dictated by existing and forecast conditions (technical, political, economic and policy). That is, analysis has led in some cases to a conclusion without other possibilities.

The air traffic control subsystem will provide an active, ground-based separation service in large portions of the airspace included in the system. These portions will be selected on the basis of traffic density, flow, speed and mix. In addition, not all of the airspace in which active ground-based control is in effect will receive the same type or degree of separation service. The system design is sufficiently flexible to permit reclassification of airspace portions to satisfy both revisions of criteria and natural development which will cause certain airspace portions to cross criteria thresholds.

This section discusses the significant design principles and equipment. techniques which have been selected.

Pilot-Controller Direct Communications

The ATC subsystem will depend upon direct pilot-controller ground-air-ground communications for control purposes. The equipment technique to be used is two-way VHF/UHF voice radio with 50-kc VHF channel separation. Since there is a shortage of radio frequencies today, the system design includes increased capability of the voice radio subsystem together with reduced need for voice transmissions. Increasing the size of enroute and terminal area sectors will reduce the number of required frequencies and frequency changes, thereby facilitating an increase in the number of aircraft that can be handled per sector. The role and feasibility of VHF/UHF data link in the ATC subsystem are still uncertain but its introduction for specific applications does not appear likely until after 1970.

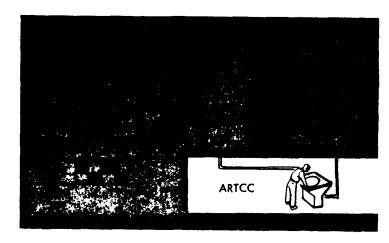


FIGURE 17 INDEPENDENCE OF POSITION DETERMINATION

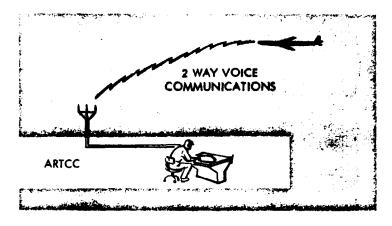


FIGURE 16 DIRECT PILOT TO CONTROLLER COMMUNICATIONS

Independent Determination of Aircraft Position

The ATC subsystem will require the continual knowledge of the position of controlled aircraft in three dimensions independent of the airborne navigation capability. This requirement can be met in the time period under consideration only by radar and/or radar beacon. The selection of these equipment techniques imposes two restrictions:

- 1. Radar and radar beacon coverage will not be available in all airspace containing aircraft under control.
- 2. Altitude information will depend on the same static pressure system and possibly the same barometric unit used to feed the pilot's altimeter. However, the information received by the ground control facilities will be independent of pilot adjustment and observation.

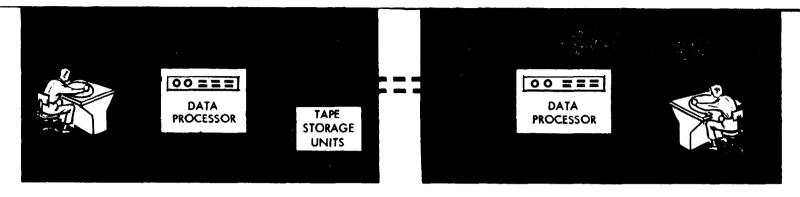


FIGURE 18 USE OF THE DATA PROCESSOR IN THE ATC SUBSYSTEM

Use of the Data Processor

As an overall design consideration, a high-speed data processor will be used to increase the controller's availability for the performance of his main duties in decision-making, issuing control instructions and keeping abreast of the air traffic under his jurisdiction. To achieve this purpose, the system design in utilizing data processing techniques will be tailored to:

- 1. Perform all routine and clerical tasks normally associated with the performance of the control function.
- 2. Act as an accurate and readily available storehouse for all information relevant to the efficient operation of the control function.
- 8. Handle the gathering of the necessary data; organize, process, correlate and filter this data; and distribute it, appropriate to the needs of the individual.
- 4. Perform the necessary investigation and preplanning, based on pilot intent, to maintain a controlled level of traffic in an orderly, safe and expeditious flow through the controlled airspace.

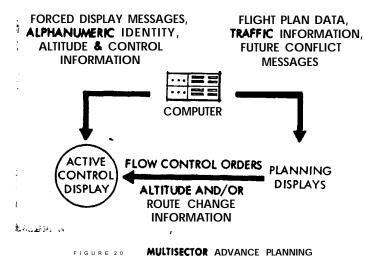
5. Provide the controller with:

- a. A clear and readily assimilated plan-view display of the controlled traffic and/or tabular display, as appropriate to his task.
- b. The necessary mechanism by which he can communicate with the machine to call-up specific items of information and to exercise control and transfer actions as required.
- 6. Continuously monitor the traffic flow and interpret the effect of significant changes so as to provide advance warning of impending unsafe situations before they are allowed to develop.
- 7. Monitor the controller's performance so as to alert him when his action or inaction would lead to a dangerous situation if left unaltered.

In addition to these functional requirements, which have been selected specifically to improve the utilization factor of the controller, the data processor is required to maintain a legal history record with a playback and data reduction capability.

Sector Size and Shape

The air traffic control subsystem is based on the use of sectors. These are volumes of airspace with defined boundaries in which a single controller, assisted by other men and machines as appropriate, has indivdual control jurisdiction over all aircraft receiving control service. The design principle for sectorization requires that the number of aircraft which can be adequately controlled per sector be increased and that the shape of the sector in all three dimensions be optimized on the basis of traffic flow, type of operation and airspace designation. The number of aircraft under control per sector will be increased by (1) making the sector boundaries independent of radar siting, (2) providing the controller with better displays of processed and organized control information, (3) reducing



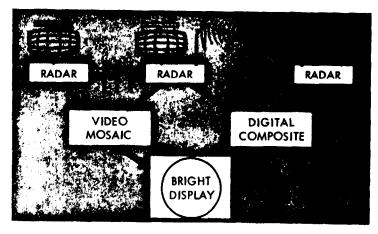


FIGURE 19 SECTORIZATION INDEPENDENT OF RADAR SITING

pilot-controller voice conversation by providing the controller with automatically identified aircraft position information and (4) advance planning on a multisector basis. Sector boundaries independent of radar siting may be achieved by utilizing video mosaic and digital compositing techniques to generate a combined radar picture from several radar inputs. Advance planning of traffic flow will be carried out by a planning control team which will assist the active control team during periods of high traffic density by recommending altitude changes and/or minor route changes for some aircraft in order to reduce the incidence of conflict situations. The number of aircraft under control per sector will be fixed by balancing control team size with the sophistication of the data processing and display system. This number will be increased to 15 or 20 aircraft per sector simultaneously under control.

Use of Radar Beacon

The system design requires the acquisition of aircraft position information for use in the ATC subsystem by primary radar and/or radar beacon. In area positive control airspace and on positive control airways, the transponder will be the principal source of position and altitude information. In other enroute airspace and in the terminal area the use of transponders will be encouraged to supplement primary radar information since the information received from a transponder will permit the controller to provide a higher grade of service. In positive control portions of high activity terminals, transponders will be required if (1) such positive control terminal airspace is feasible and practicable and (2) if the SLATE development results in a technically and economically suitable device.

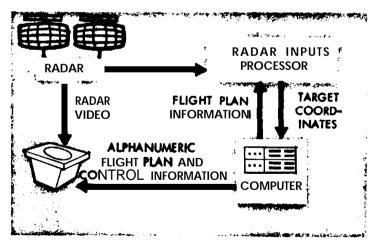


FIGURE 22 AUTOMATIC RADAR TRACK/FLIGHT PLAN CORRELATION



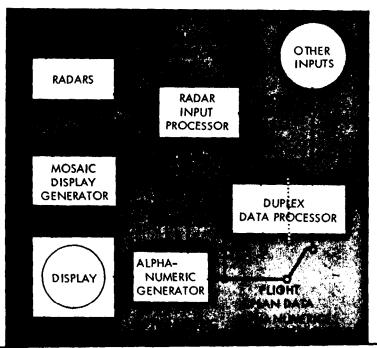
FIGURE 21 POSITION, ALTITUDE AND IDENTITY DETERMINATION

Automatic Radar Track/Flight Plan Correlation

Automatic correlation of aircraft identity and altitude with radar track data is provided to reduce controller workload and increase safety. Identified radar tracks are generated on the displays by using a radar inputs processor to derive radar position and a computer to relate this position to the appropriate flight plan. The radar tracks may be generated on the display utilizing either the digital output signals of the radar inputs processor or the combined radar video signals from the mosaic generator. where radar track data are available, the alphanumeric information is presented adjacent to the actual radar track. When radar track data are not available, the aircraft position is estimated by extrapolating updated flight plan information in the computer.

Composite Display

A design principle states that the sector size and shape will be determined by traffic flow, type of operation and airspace designation. This principle led to the selection of a type of controller display that permits the control team for each sector to see all of the aircraft under its jurisdiction on a single plan-view display which contains appropriate alphanumeric information. In many cases, sectors will be made up of airspace in which there is no radar coverage, along with airspace with single or multiple coverage. These considerations led to the choice of an equipment technique which permits a plan-view display to show extrapolated flight plan position data on some aircraft along with radar position data from different radars on other aircraft.



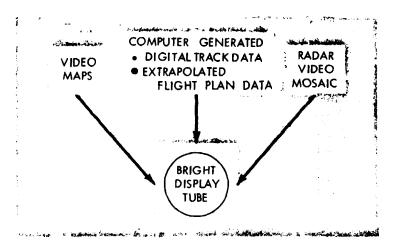
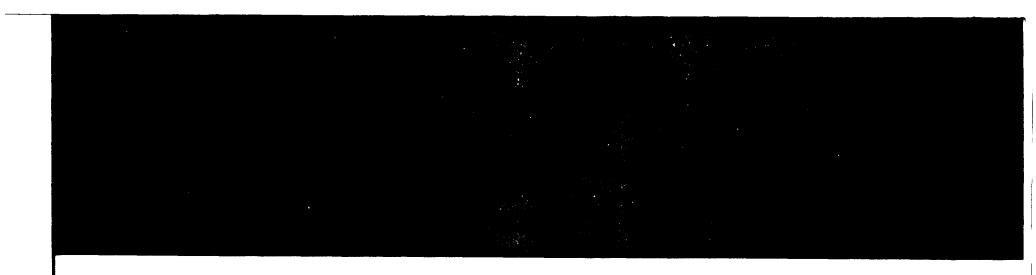


FIGURE 23 COMPOSITE DISPLAY

Fail-Softly Equipment Complex

The ATC data processing and display subsystem configuration provides several independent data channels between the acquisition devices and the control displays. The use of separate channels provides not only reliable operation in that unit equipment failures only degrade the display but also the flexibility required for system growth through progressive implementation. Adherence to the fail-softly principle resulted in the use of independent channels for video and alphanumeric information. Further, the radar inputs processor and alphanumeric generation channel is independent of the data processor so that tracking and "radar track/flight plan" correlation may be maintained when the data processor is off-line. The data processor itself contains parallel paths and internal redundancy.



With its ability to handle and store large amounts of data, to analyze, 'process, filter and distribute these data in a form suitable to the system operator, the high-speed data processor is an ideal tool for use in the ATC subsystem. However, considerable care must be exercised when integrating this electronic machinery into the total system complex in order to utilize its full potential and assets in conjunction with those of the controller and other components of the system. The design is sufficiently flexible to allow for various degrees of automation as required by the type of service to be provided and the traffic densities and mixes in the different parts of the country.

The equipment configuration that is described in this section was selected on the basis of fulfilling the operational

requirements of the ATC subsystem as they exist today and can be predicted for the period extending through 1975. In addition, this configuration uses only those equipments employing present state-of-the-art techniques since prolonged development efforts would severely restrict an early implementation program. As specific functional portions of the system are developed, tested and "debugged," these will be installed in the field. This process prescribes for the field an implementation program of an evolutionary nature to permit a gradual buildup marked by an increasing degree of sophistication and capability. The intermediate operational installations must, therefore, be developed with sufficient flexibility (modular add-on capability) to accept the further improvements that will be successively installed.

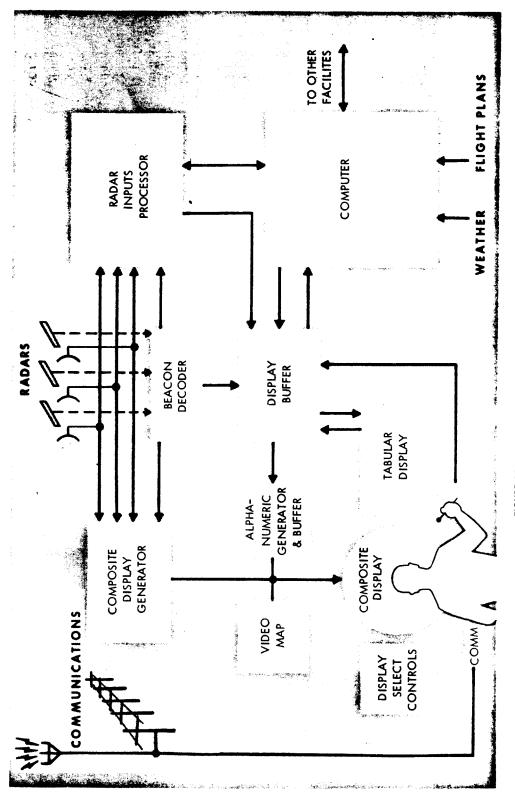


FIGURE 25 AIR TRAFFIC CONTROL SUBSYSTEM

ATC Subsystem Configuration

The functional configuration that resulted from the system design choices is shown in Figure 25. As seen from the simplified diagram, several independent data channels are used in supplying information to the operator at his display console. Primary radar and radar beacon information is displayed through a video channel employing the mosaic display generator and through an independent digital channel employing the radar inputs processor. Alphanumeric information, associating aircraft identity and altitude with the radar targets, can be accepted for display directly from the beacon decoder or from the information generated by the computer. The use of several independent data channels to feed the display devices results in a high degree of system reliability.

The displays and their associated data entry devices become the interface between the controller and the data processing and radar portions of the air traffic control subsystem. Ground-air-ground communications form a part of the interface between the controller and the system by giving him direct access to the pilot. The display system employs two basic types of displays:

- 1. An advance planning display on which information of a long-term nature such as future traffic buildup, future incoming and outgoing traffic, traffic densities and distributions by route and/or area, and others, is displayed to the planning controller.
- 2. An active control display on which an accurate and dynamic plan-view picture of the controlled traffic is presented to the active controller.

The active control displays are capable of presenting: (1) a filtered plan-view display of controlled traffic using only processed data from the computer, (2) primary radar and radar beacon video or (3) a mixture of video and computer information. Both the planning and active control positions use automated tabular display equipment in place of flight progress boards to present computer-generated flight plan data and control information. Function-message keys located at the display consoles permit the controller to call up various displays of tabular data, effect coordination activities and enter data into the computer.

In considering the nature of the central data processor, apart from any specialized peripheral hardware associated with it, certain general observations can be made. If a complete and exact specification of the full system design were now available and further if it could be guaranteed that the design were final, requiring no major changes, then a special-purpose, wired-program machine could be built to satisfy the requirements at a cost considerably less than that of a general-purpose machine. This is because the logical units can be tailored to the specific requirements of each individual function.

Since complete and exact specifications are not available and since industry already has in production a large variety of general purpose computers, the above discussion provides only an indication of the method to be used in selecting the data processing configuration appropriate to the requirements. In general, an examination of those functions requiring high data rates for processing (e.g. automatic tracking) will be made to determine whether they can be more economically performed by a specially tailored com-

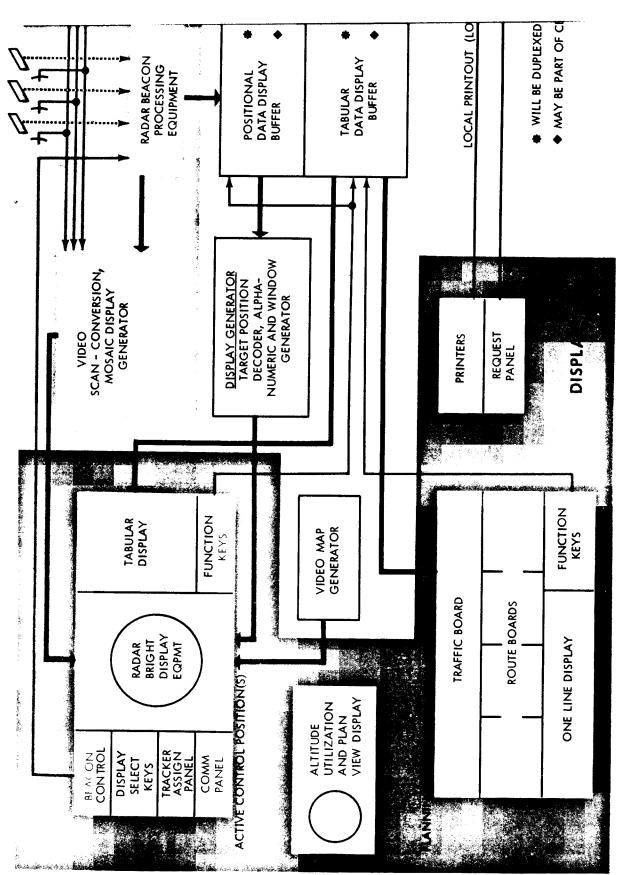
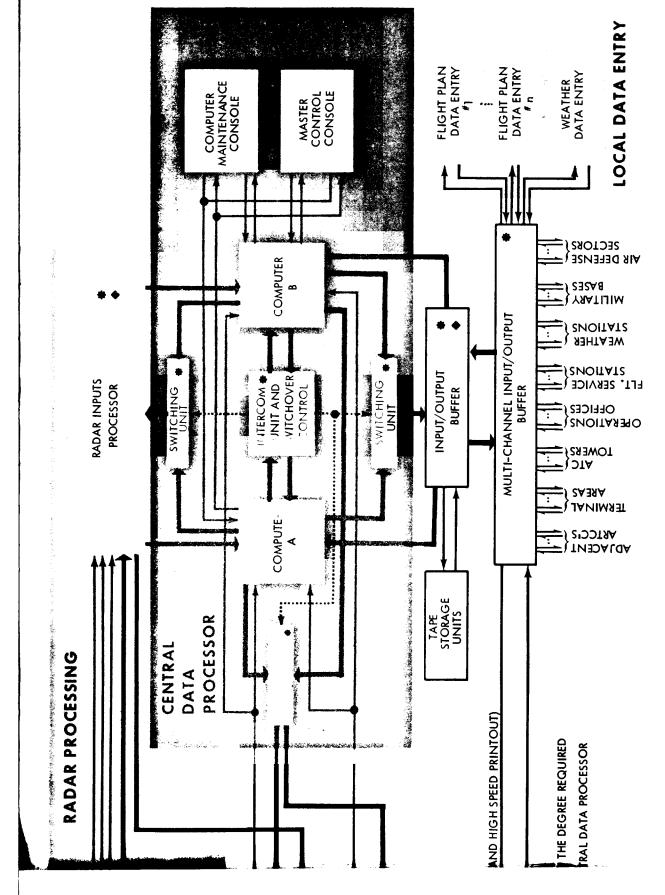


FIGURE 26 AIR TRAFFIC CONTROL SUBSYSTEM DETAILED FUNCTIONAL BLOCK DIAGRAM



puter rather than by the central general-purpose computer. This would also permit implementation of a fail-softly concept as failure of the specialized machine would degrade the system by only that percentage which the particular function contributes to the overall system performance. Hence, the radar inputs processor is shown in the diagram as being separate from the central computer.

Detailed System Description

The functions of the subsystem elements and their relationship to the system will now be described with the aid of the more detailed block diagram of the data processing and display functional configuration illustrated in Figure 26.

The input/output buffer coupled with the multichannel input/output converter provides the interface through which the automatic external coordination and information exchange with other elements of the system is accomplished. The majority of the internal requirements for coordination and message exchange between control positions are handled through the data display buffers. Voice communications, landline and ground-air-ground, complete the requirements for coordination and information exchange and provide the independent channels for increased reliability. The central data processor receives numerous inputs from a variety of sources. These input messages, which include such message types as flight plans, clearance requests, control messages, control transfers, weather and modifications thereof, must be accepted, stored and processed by the computer. In addition, primary radar and radar beacon inputs are accepted and processed by the radar inputs processor in conjunction with the central wmputer.

To achieve the necessary reliability and to provide for scheduled and unscheduled maintenance on the computer, a duplexed computer configuration will be required. To insure adequate computer availability, the individual computers must be capable of operating error-free for extended periods of time with a minimum of down-time during periods of unscheduled maintenance. There are some reservations as to whether the presently available "off-the-shelf" computers can satisfy the requirement adequately without some degree of modification. Certainly, those critical elements in the data processing system that have an effect on a number of processing function8 will require special attention in the matter of reliability. Also, full advantage will be taken of techniques for error-checking and error-correction. In addition, diagnostic routines will be included in the computer program to assist in locating faulty units.

Flight Plan Entry

The filed flight plan, defining the pilot's intent, is received either by voice, teletypewriter or special data link between facilities. This information after processing will include aircraft identity, type, ground or true airspeed, assigned beacon code, type of service (IFR, CVR, CVFR, VFR), point of departure or entry, route structure including airways and/or fixes, altitude desired, point of destination and remarks (e.g., navigation and wmmunication equipment on board). Those flight plans received by voice will be entered into the wmputer by an operator through an alphanumeric keyboard entry device. Others will be fed directly on-line into the computer through the multi-channel converter capable of rate changing and wde translation. Ap-

propriate error detection and error correction techniques will be employed to insure that the flight_plan information is received- correctly by the computer,

Storage and Maintenance of Adaption Data

The data-processing system must take into account the environmental geography, center and sector boundaries, location of radar sites, navaids, airports, airspace structure, location of airways and fixes along the airways and specially designated areas. These data, relevant to the performance of the data-processing functions are stored by the computer in a common set of system coordinates established for the environment. As changes are introduced into the environment, the data-processing system will be capable of accepting these changes and incorporating them into its computer program logic.

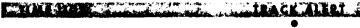
Flight Plan Extrapolation

All flight plans entered into the computer will be broken down into route segments based on fixes along the intended route of flight. The estimated time of arrival (ETA) over these fixes will be calculated and stored by the computer. The calculation will use true airspeed and winds aloft data and will take account of the climb or descent profile of the aircraft. Based on this information, an aircraft's present position is calculated for all active flight plans. This extrapolated flight plan position of the aircraft will be made available at the control displays and provides positional information to the controller independent from the radar.

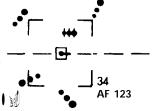
Automatic Correlation of Radar Track and Aircraft Identity

Primary radar and radar beacon data from a number of separate radars are fed to the radar inputs processor. Radar information received as video will be converted into digital form so that all information will be in a standard machine language. The ATC subsystem is a cooperative environment, where advance information is available on aircraft requiring control service. Thus, it, is feasible to reduce the storage requirements and facilitate the processing of radar inputs by the application of a "gated window" principle whereby only those target returns within a limited area of the extrapolated flight plan position would be accepted by the radar processor. For this purpose, the extrapolated flight plan position is made available to the radar processor from the central data processor. The use of beacon identity and altitude will of course greatly facilitate this filtering process. As soon as tracking has been established on an aircraft, the size of the window can be reduced by replacing the extrapolated flight plan position with the updated track position as the window reference. Since a composite radar display of the controlled traffic is required to permit flexibility in sector size and shape, the radar target coordinates will be converted to the common system coordinates.

In the automatic tracking function, the maintenance of track identity will be done automatically by the computer. However, for an aircraft first entering the system, the controller will be responsible for initiating the track after positive identification has been established (for aircraft



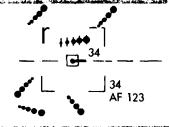
Computer alerts controller that AF 123, assigned beacon code 34, is about to enter the system ond requires track initiation. Partial route disploy shown. Rectangle shows area in which A/C return expected.



150

Controller has completed identification and initiates a mdor track. Superfluous information hos been erased from display. Controller has called-up altitude informa- 1' + @ % 1 2 3 tion (15,000 ft.). No conflicts are shwn.

Some os before but more history informotion avoilable on rodar returns. Code call-up by computer on beacon return shows'it to be code 34.



Track position automotically updated.



FIGURE 27

REPRESENTATIVE DISPLAY SYMBOLOGY-RADAR TRACKING

equipped with 4096 code transponders, this function may be assumed by the computer).

Figure 27 illustrates a sample sequence of events in the automatic-tracking function. When a radar track has been initiated, an appropriate tracking symbol appears on the display. As with flight plan position, this track position is extrapolated in real-time in accordance with a velocity and course vector determined from the flight plan information. As mentioned before, the track position is used as the reference for correlating new radar returns with the radar track and is itself updated as required by the selected radar returns.

These radar returns will be stored as positional data with a time tag, radar site identity and aircraft call-sign to which the radar return is to be associated. Overlap radar coverage will contribute to multiple returns on the same target. To eliminate the resultant clutter and possible confusion and yet retain the advantages of redundancy offered by the multiple coverage, the processor will classify the returns in order of preference and display only those required to produce continuous coverage using an area priority arrangement as the basis for selection.

Where VFR traffic advisory service is required, the following methods are employed:

- 1. During periods of light, traffic, the size of the window is increased about the aircraft of concern to allow the controller to sea the uncontrolled traffic.
- 2. In areas of heavy traffic, a separate display is provided from which relevant traffic can be gated to the active control display.

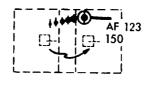
Flight Plan Updating

This function should not be confused with track position updating which is done to keep the tracking symbology in association with the selected radar returns. The main purpose of flight plan updating is to keep the flight plan information current. Thus, if altitude changes, route changes or any other significant changes are introduced, the flight plan must be updated to reflect these. Such modifications are inserted into the computer by control personnel.

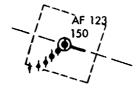
There are other types of deviation from the flight plan on which advance information is not available but which have a considerable effect on the management of airspace. The

FIGURE 28

Radar track position is advanced longitudinally from the extrapolated flight plan position beyond prescribed limit. Computer automotically updates F.P. position, calculates new ETAs and probes for possible conflicts. F.P. position is not displayed.



Controller talks to pilot to verify intent. Modifies Flight Plon route using radar track position as intermediate fix. Computer then automatically updates F. P. position to track position. F. P. position not displayed.



current flight plan information is essentially a statement of the pilot's intent and in a sense represents a contract between the pilot and controller. The computer's role in this operation is to:

- Continuously monitor the path made good.
- Compare it with the intended path.
- Update the extrapolated flight plan position.
- Probe for developing conflict situations.
- Alert the controller when the allowable deviation has been exceeded.
- Display information that will assist the controller in resolving conflict situations.

Figure 28 illustrates some of these computer actions.

Radar track position has gone out of association laterally with the F. P. position. Automatic update action is inhibited. Conflict probe using radar track position as intermediate fix shows no conflicts. F.P. position is displayed.

Controller is alerted that o radar handoff action is required. Transfer of control will be given over to control team 2.

REPRESENTATIVE DISPLAY SYMBOLOGY-FLIGHT MAN UPDATING AND RADAR HANDOFF

Planning Function

The air traffic control planning function consists of advance and short-term planning. Although both types of planning are concerned with the safe utilization of airspace, the first type deals with a broader scope of activities where consideration must be given to future traffic buildup, distribution of workload, long-range resolution of possible conflict situations, maintenance of a safe level of operation in all sectors, effect of control decision in one sector on another's operation, and center-to-center and center-toterminal coordination for the prevention of overload situations. The second type of planning is concerned with a smaller area of the airspace and deals mostly with the active control of aircraft. This type of planning considers the present separation between aircraft and will be done by sector oontrol teams. To assist the advance planning controller in the performance of his role, the computer will generate tabular displays showing future traffic densities and distributions and predicted delays. In addition, a plan-view display of the future air traffic picture may be made available to the controller.

Conflict Prediction

The computer will be required to perform conflict prediction on each controlled flight when it enters the system and on each flight that has required an update action. Advance planning and active control require long-term and short-term conflict prediction programs to be carried out by the computer. The separation minima for radar control are the same for both and are dependent on the

fine-grain data given the controller. To establish the conflict prediction criteria, the prediction error as a function of time must be added to the separation minima. This prediction error is directly related to how accurately the aircraft will conform to a prescribed course. This type of error can be broken down into lateral and longitudinal components with respect to the flight path. The lateral error is a function of pilot performance and the accuracy of the navigational equipment. The longitudinal error is affected by pilot performance, instrumentation errors, wind effects and time references in the system.

In the absence of radar data, nonradar separation minima will be used in determining the conflict prediction criteria. Thus the system will be capable of providing separation service when no radar data are available.

Transfer of Control

Since the system provides extensive radar coverage, many control transfers will be accomplished using a positive transfer of control action with automatic radar handoff.

The computer will be required to initiate the transfer of control procedure. As soon as the aircraft reaches a specified distance from the sector boundary, a handoff symbol is generated adjacent to the track position on the display of both sector controllers. The transferring controller will take positive action by pushbutton to indicate to the receiving controller through his tabular display that he has initiated the handoff. Because of the display techniques used, both controllers will have identical information in this area of the display. Additionally, the computer will

display to the receiving controller the present flight plan position and a partial route display. The flight plan information will appear on his tabular display. A pushbutton action on the part of the receiving controller will signify that he has accepted control, and the alert signal will be erased. A separate action will be required for erasure of the partial route and flight plan display to insure that the controller has examined this area. When no radar data exists for the aircraft, the above procedure will be identical except that the handoff symbol will be placed adjacent to the displayed flight plan position.

Sequencing

The marshalling controller, who is responsible for sequencing aircraft in the terminal area, will have a tabular display showing all proposed departures and arrivals. To assist him in the ordering task, the computer will transmit information to his display on incoming aircraft including identification, type and runway threshold ETA. This ETA is calculated by the computer for an unrestricted approach with an assumed descant profile consistent with the type of aircraft concerned and taking into account the winds aloft and landing direction.

The processor will sequence the order of takeoffs and landings and designate the time for each. The designated time of arrival for an aircraft is used by the computer to determine the delay which must be absorbed either enroute or during descant.

When an aircraft approaches the terminal entry fix, an automatic handoff is initiated to the sequence controller.

The computer will maintain automatic tracking on the target, display the identification and altitude symbology and generate the time the aircraft is required to depart from the entry fix. As the flight proceeds on the descent path, the computer monitors its progress relative to the planned arrival time to determine deviations from the desired flight path and indicates to the controller the required speed reduction, resequencing or track changes.

In the final vectoring area the computer will generate aircraft identity, altitude, speed reduction instructions and either a plus or minus time indication of aircraft status, or heading vectors for display.

Data Recording and Playback

A record of the information displayed at each controller's console, controller 'actions taken at the console, position of display selection switches, computer responses and controller communications will be maintained for legal and statistical record purposes. Storage of the necessary information will be accommodated in such manner that a playback of any individual controller's plan-view display of controlled traffic and tabular displays can be rerun for any specified time interval. Additionally, time of recording will be continuously displayed during any playback period.

With the above capability, a careful review of operator and machine performance can be made. This will permit detection and analysis of problem areas and provide possible feedback for improvements in the system. Playback recordings can also be used to good advantage for simulation activities and for training purposes.

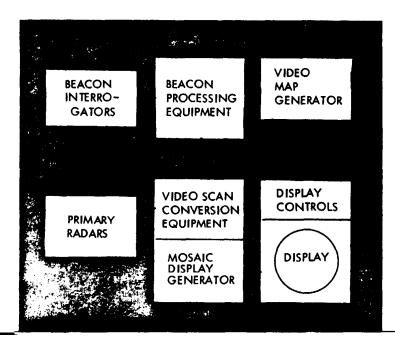
Display Subsystem

The display subsystem consists of tabular planning displays and plan-view active wntrol displays. The latter present a composite picture of video map, radar video, beacon alphanumeric and computer-generated alphanumeric and position data. These data reach the display through the independent channels shown in Figure 26. Video map information may be generated in TV scan coordinates in the video map generator or it may be prepared in the display generator using computer coordinate information. Similarly, radar track data may be presented on the composite display either by using scan conversion equipment to convert the radar video signal to TV coordinates or by using the radar inputs processor and the display generator channel. In the latter case, the radar video is converted to digital x, y coordinates by the radar inputs processor and to symbolic form by the display generator. Still a third data channel exists through which computer information (i.e., extrapolated flight plan data and suggested control instructions) may be presented on the display. This channel utilizes the display buffer and display generator to convert digital computer messages to TV display formats. As a further aid in achieving a high degree of system reliability, the tabular display subsystem, which presents flight plan information and a repeat of computergenerated control instructions, utilizes an independent display buffer and computer input/output unit. This storage and computer interface unit also handles controller-generated messages relating to the execution of control instructions or the modification of flight plans.

Display Video Channel

The display video channel in the display system (Figure 29) is comprised of the scan conversion, mosaic display, video map, beacon processing and display equipment. This subsystem permits the controller to select all primary radar, all radar beacon or selected radar beacons returns. Video targets selected for display are converted from PPI to television coordinates utilizing high resolution, scan-conversion equipment.

The television technique of taking portions of the scanconverted pictures from several radars and combining them in mosaic form was selected to meet the system goal of flexible sectorization. A sync phasing system is utilized to establish the proper spatial relationship between the radar sites on the displays and blankingmasks are used to select the desired video coverage from each radar's scan-



converter. Generation of video maps may be done using presently existing TV map generators.

Beacon processing equipment is utilized to permit the controller to display aircraft by selected codes. By judicious assignments of codes, aircraft may be selected by altitude strata, direction of flight and similar classifications.

Radar Beacon Alphanumeric Channel

Airborne transponder codes are converted to alphanumeric form for display by the radar beacon alphanumeric channel equipment. This channel, shown in Figure 30, is wmprised of the beacon processing equipment, active control display buffer, display generator, keyboard and display. A common display format and storage unit accepts and stores transponder code and digital position information on each cooperating aircraft from the beacon processing equipment. Since the storage is wmmon to all displays, the format equipment routes the beacon data to the proper portion of the storage surface associated with each display unit in accordance with target position. Each display group has its own display generator which converts the digital position and beacon identity codes to alphanumeric characters properly positioned on a buffer storage surface in that device. The characters are generated in the sequence that they are received from the storage unit and are retained in the buffer store for subsequent readout in synchronism with the television scan of the display device. Updating of the target position is done at the rotation rate of the radar when the beacon alphanumeric system operates independently of the computer. Transponder altitude information is displayed with the beacon or aircraft identity

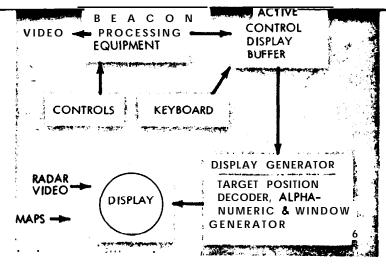


FIGURE 30 RADAR BEACON ALPHANUMERIC CHANNEL

alphanumeric group. The controls associated with the beacon processing equipment provide the controller with the capability of displaying alphanumeric information on transponder-equipped aircraft operating on selected codes.

Computer Alphanumeric Channel

The computer alphanumeric channel, shown in Figure 31, includes the radar inputs processor, computer, active control display buffer, display generator and display unit. Position information in digital form is derived from the primary radar video by the radar inputs processor for non-transponder-equipped aircraft being tracked for control purposes. These data are fed to both the active control display buffer and the computer. In addition, beacon code and target position data are fed to the computer. The computer correlates aircraft identity with radar track position, generates necessary control instructions and formats the

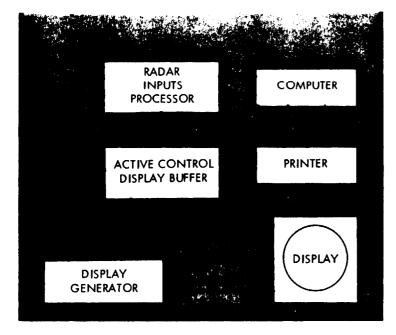


FIGURE a1 COMPUTER ALPHANUMERIC CHANNEL

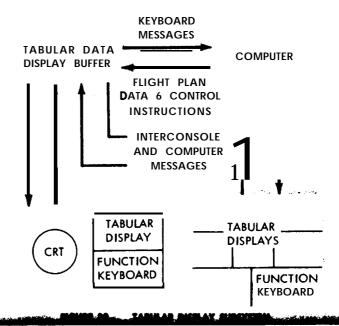
alphanumeric text for display. The display message format is transmitted to the active control display buffer where it is stored with the target position coordinates. The display generators convert the digital information to display formats as described above.

The computer also operates hard copy printers located at or adjacent to the control positions. These printers and their associated data request keyboards are connected directly to input/output channels of the computer.

Tabular Display Subsystem

The tabular display subsystem, shown in Figure 32, includes the tabular displays at the active control consoles, the tabular planning displays, a tabular data display buffer and the computer. The tabular display subsystem operates

directly from the computer and represents a data transfer and display subsystem that is independent of the one associated with the cathode ray tube displays. Computer generated control instructions are transmitted to the controller via both the cathode-ray tube and tabular display subsystem to protect against equipment failure. A common tabular data display buffer storage unit is utilized to service all tabular console displays. Function/message keyboards and function pushbuttons located in the lines of tabular data permit the controller to format and transmit messages to the computer or to other consoles with a minimum of effort. The tabular displays present abbreviated flight plan data and computer or controller generated control instructions in a time or altitude sequence as selected by the controller. Planning displays use fix/time, fixed/altitude, sector time or sector/altitude formats.



Man-Machine Relationship

Before it is possible to describe the operational use of the system, it is necessary to define the extent to which man is assisted by the data processing subsystem in carrying out the control functions in the system that is to be in operational use in 1975. The areas in which computer assistance will be utilized are summarized below:

1. Flow Planning

- a. Generate traffic density, flow distribution and airport delay information and format for display.
- b. Receive traffic flow restrictions from other centers and format for display.
- c. Generate computer recommendations on flow restrictions and flow diversions to prevent controller or facility overload and format this information for display.
- d. Accept and remote to other centers or control consoles the flow restriction actions initiated by the flow control planner.

2. Centralized Traffic Planning

- a. Accept, error check, process and store flight plan data.
- b. Accept aircraft profile, weather and ground-environment status data.
- c. Use data gathered in (a) and (b) to compute route ETAs.
- d. Conduct planning type conflict searches for each aircraft at the time the clearance is issued and at periodic intervals thereafter.
- e. Generate and format data for tabular planning

displays including abbreviated flight plan data, time adjustment stack status and scheduled traffic over defined points and designated routes.

- f. Format flow control messages for display.
- g. Remote and format for display the planning actions selected by the centralized traffic planning controller to the active controller for execution.

3. Active Control

- a. Extrapolate flight plan position and generate information necessary for display of extrapolated flight plan tracks.
- b. Format display messages to present radar track and alphanumeric flight plan and control data on the CRT displays.
- c. Accept aircraft position inform&ion from keyboard entries, joystick inputs and radar tracking equipment and use them to update flight plan information.
- d. Conduct real-time conflict searches, using separation criteria based on the type of control, to detect situations in the near future that will result in violations of separation minima if allowed to persist, prepare valid solutions to resolve the conflict and format the control order message for display.
- e. Conduct periodic evaluations of the controlled traffic situation and review each controller's actions to detect situations that require control actions and to assure that routine control actions are carried out promptly.
- f. In terminal areas, schedule all inbound and outbound traffic and generate resequence, hold, route

change, speed reduction and vector orders as necessary to obtain optimum tragic movement rates. g. Automate the transfer of control and radar hand-off functions.

It should be noted that not all of these functions will be provided in all airspace nor will all equipment be installed in the same time period. Traffic density and type will determine the necessity for installing terminal area sequencing. Equipment development and computer programming may delay those functions which depend on the installation of the primary radar tracking capability and the preparation of the more complex programs. The latter are associated with providing computer assistance in the decision making functions. The controller will retain the responsibility for the selection and issuance of all control orders whether proposed solutions were generated by the data processor or not.

Types of Display

Functionally, two types of display are required to implement the planning and active control positions. Tabular displays will be provided for:

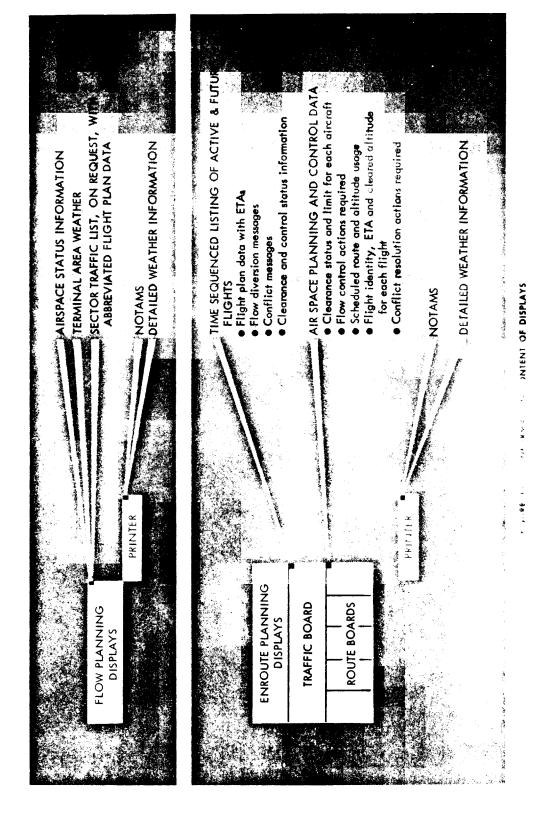
- Planning and remoting of the appropriate portions of the plan to the active control positions.
- Presentation of flow control and terminal area delay status information to the planning controllers.
- Presentation of abbreviated flight plan data displays at all positions on demand.
- Presentation of computer-recommended control instructions.

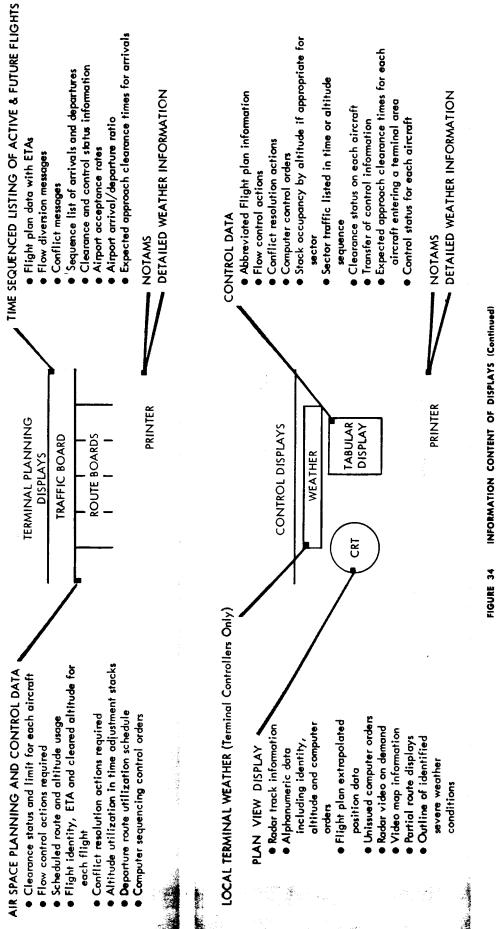
- Planning and control of time adjustment stack utilization.
- Indication of aircraft clearance status.
- Coordination of transfer of control responsibility on each aircraft.
- Sequence and schedule lists of arrival and departure terminal area traffic.

These displays will contain function keys associated with the alphanumeric data to permit the controller to communicate with the computer to acknowledge issuance of computer-generated orders, modify clearances (reroutes or altitude changes), block airspace, indicate aircraft status changes and direct control actions to active control teams.

Bright cathode ray tube displays will be utilized to present control information to the controller having direct jurisdiction over the flight. This information will include video map data and forced displays of situations requiring controller action. Since the problem with cathode ray tube displays is one of introducing too much information onto the display, the controller will be provided with display select keys to allow him to select the information desired. Further, beacon decoder, tracking gate assignment, and joystick handoff marker and position-reporting controls will be provided.

In addition to the two major types of displays described nbove, several special types of tabular and printer-generated displays are required to present flow control, weather sequence, local airport weather, NOTAM and facility status information. Figures 33 and 34 show the relationship between the types of displays and the information displayed.





1

Advance Planning

The basic planning goal is to increase the number of aircraft that a controller can handle simultaneously. Progress toward this goal can be achieved by instituting a type of planning that reduces the peak conflict incidence rate to a number that is within the controller's capability to resolve while still controlling a large number of aircraft.

Since the incidence of conflict peaks is closely related to traffic density and the separation minima in use in the area, the advance planning function will be done on the basis of providing a form of flow control that will allow the planning controller to reorder traffic (change altitude or reroute traffic to less dense sectors) when it approaches a level close to controller saturation in a particular sector. As a result, the longer-range planning function will be carried out for an area that is larger than a single sector.

The computer will assist in the enroute area by conducting conflict probes to detect the necessity for modifying the flight plan. In the terminal area a greater burden of responsibility falls on the planning controller due to the descending/ascending flight tracks which terminate on the approach path or at the entrance to the enroute area. Here the planning controller must, plan on a traffic density or fix/altitude basis rather than a fix or area/time basis during periods of high traffic density.

Display of Planning Information

The information required by the controller for the advance planning function will be presented to him through his

displays in an easily interpretable and readily usable form.' Some types of information change little from hour to hour, while other types are current only for relatively short periods. The former may be printed out at periodic intervals as "hard copy" by a printer located at the planning position. Examples of this type of data include detailed weather sequences, forecasts and winds aloft reports; NOTAMS covering status of the environment; and some types of long-term flow restrictions. The other types of data which are closely associated with aircraft flight path and pilot intent will be presented on automatically posted tabular displays. This type of data includes pilot intent. clearance information, flow control information, computer generated control orders and conflict solution data. The information displayed at each planning controller's console is best understood by examining several of these positions.

The flow control planner will be provided with a printergenerated hard copy of weather sequences and NOTAM data and possibly a special television display of selectable weather information. Local weather information will be presented in alphanumeric form on a posting board on the console for the metroplex airports in the center area. Tabular displays will be provided for metroplex terminal traffic, sector traffic, flow control orders and diversion orders issued to the other planning controllers. The diversion orders display is a "call up" type display which permits the flow controller to view the traffic scheduled through any sector (or over any posted geographic reporting point) when the sector traffic board indicates that traffic will peak above sector capacity. After reviewing the situation, the flow controller may resector by transferring a part of one sector area to another controller where communications coverage is available or he may reroute some of the traffic through a different sector. A keyboard associated with the diversion orders board will be used to enlist computer aid in rerouting traffic.

The planning console for enroute sectors will contain displays of future flights (traffic board); route boards covering major route intersections; a function keyboard for reroutes, altitude changes and clearance issuance; and a one-line display for verification of control orders to be transmitted

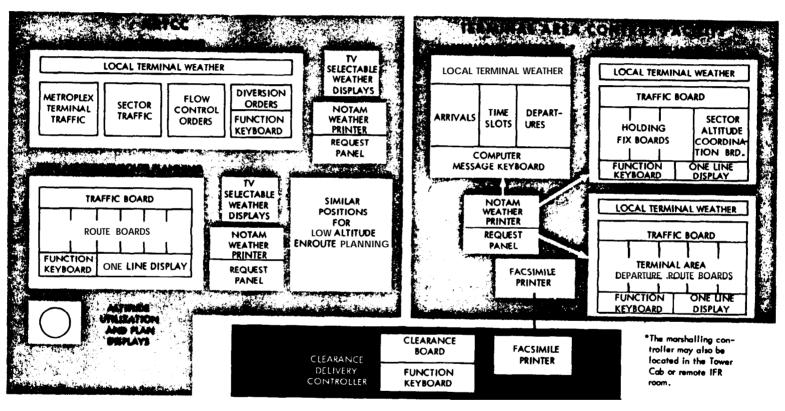


FIGURE 35 PLANNING POSITION DISPLAYS

to the active controllers and the data processor. A printer located near the console will prepare hard copy printouts of NOTAM and weather data. The route boards serve as a situation display of the computer proposed solutions when the computer is on-line and are the devices by which advance planning may be continued by the controller when the computer is off-line for any reason. The keyboard provides reroute and altitude change keys to permit the controller to resolve conflicts manually or to modify traffic flow patterns to reduce the workload of the active controllers.

Metroplex terminal area planning will require the services of a control team to carry out the functions of marshalling traffic, planning arrival and departure traffic flow and delivering clearances to pilots. Arrival and departure planning is performed on a centralized basis for all the airports within the metroplex terminal area. In general, one or two controllers can carry out the planning function associated with the metroplex traffic including satellite airport traffic receiving control service. Once the marshalling controller has assigned or approved computer-generated schedule times, these are remoted to the arrival and departure planning displays as well as to the data processor. The arrival planning console is equipped with a traffic board and fix postings for the holding fixes which, in general, also serve as the feed points for the airport. These fix postings become holding stack boards when terminal area traffic exceeds the airport acceptance rate. The arrival controller assigns holding altitudes and expected approach clearance times (EACs) for aircraft delayed at these points.

Metroplex departure planning will use a traffic board and route boards. The latter will post first enroute fixes or geographic points near the end of each of the terminal departure routes. Figure 35 presents a summary of displays provided at the planning positions.

Display of Active Control Information

The controllers at the advance planning consoles do not control aircraft, but assist the active controllers by carrying out the advance planning function; therefore it is necessary to remote the plan to the active control positions for implementation. The remoting, carried out through the tabular display system, presents the plan and the modifications which require control action on the tabular displays located at the console of the active controller who must carry out the indicated control action.

The active control position console contains a cathode ray tube display with associated display select keys and tracking system controls and a tabular display with associated function keys which permit modification of the plan, position reporting, control transfer, altitude blocking and other functions. The tabular display is a "call up" type display whereby the controller may display the trade presently in his sector and predicted traffic that will enter in the next 5 minutes, either in altitude/time sequence or in time sequence of entry, at his option. In addition, he may call up a display of traffic over any fix in the center's area in either fix/time or fix/altitude format. His tabular display provides advance warning of incoming traffic, a picture of the present load, a method of quickly determining whether an altitude or route change is the best way to resolve a conflict and a backup capability in oase of loss of the radar

display. For those sectors that contain time adjustment stacks, the console will also have a holding stack posting board that provides a control interlock with the display on the terminal area arrival planner's console and the one on the sequence controller's console. Figure 36 shows the

holding stack board interlock system and transfer of control configuration associated with the enroute and sequence controller positions. Several tabular displays of limited data presentation capability are also provided. These displays, located on the consoles of the final spacing controller

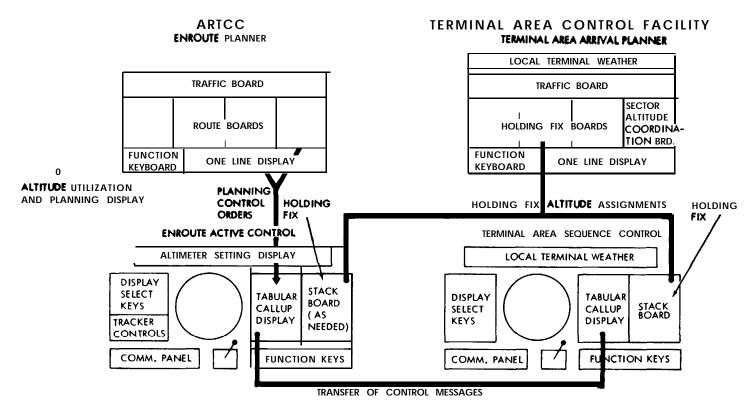


FIGURE 36 ACTIVE CONTROL DISPLAY INTERCONNECTIONS

and local controllers in the tower cab, provide these controllers with a sequential listing of inbound and outbound traffic, with a repeat of the control orders for arrivals and an indication of departure direction for departures.

Plan-View Displays for Active Control

Bright, flicker-free, television-type displays will be provided at each active controller's position to present a planview of the controlled traffic with alphanumeric identity, altitude, handoff symbols and computer-generated control order information. Certain information will be presented on the cathode ray tube as a "forced" display relating to control actions that must be carried out to prevent dangerous situations from developing. Other data will be available on a controller-selectable basis. Forced displays include outlines of severe weather, turbulence and/or precipitation: data blocks on aircraft requiring control action to resolve conflicts, to accept control or to adjust flight path; and symbols identifying the present radar or extrapolated flight plan position of the aircraft. The data blocks will present aircraft identity, altitude and the control order to be given. If the control order involves several aircraft, supplementary data may be presented in alphanumeric form in an area on the CRT display reserved for that purpose. Selectable displays include video maps, all primary radar video targets, synthetic data only, extrapolated flight plan tracks showing a portion of the route, rectangles about each target representing the separation criteria used for conflict prediction and special information, such as cloud contours at selected altitude levels to simplify CVR/CVFR control. A panel of display selection keys is provided to allow the selection of any or all of the above data. Additional flight plan information may be called up in the data block, such as next fix and ETA, next route segment and destination.

The normal mode of system operation utilizes the data processing subsystem to extrapolate flight plan or radar tracks for presentation on the display. The processor also supplies the identity, altitude and control order information which are displayed adjacent to the radar track or extrapolated flight plan position. The display shows a special symbol to indicate the position of each transponderequipped aircraft that has an associated data block. The data block is located adjacent to a "window" which allows radar video to appear on primary radar targets, or to the special symbol for beacon targets, and may be positioned in several locations about the window or symbol at the option of the controller. If, for any reason, the primary radar or radar beacon return from the site normally supplying position data in an area of a display is lost on a single target, the computer may switch to tracking the same target on another radar covering the area. In this case, a special symbol will be displayed adjacent to the target location to indicate to the controller that alternate radar coverage is being used to maintain the track. The positions of aircraft flying below radar range and of non-transponderequipped aircraft obscured by weather will be indicated by a special symbol that accompanies the data block as it moves in accordance with the updated flight plan.

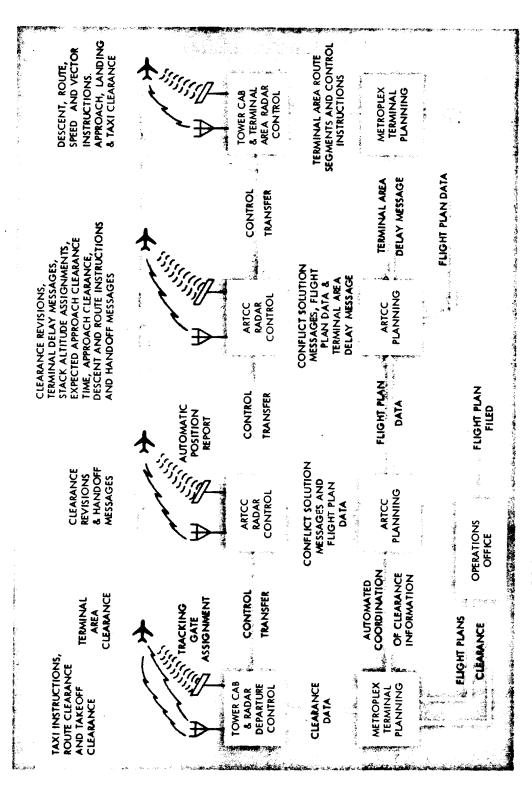
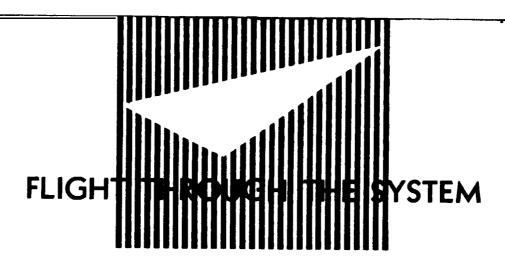


FIGURE 37



This section illustrates the utilization of the automated ATC subsystem for the control of an aircraft on a typical flight in the system that will be in use through 1975. Figure 37 shows in simplified form the different ATC functions accomplished during the course of that flight from takeoff to landing. The diagram indicates how the following design objectives are satisfied:

- 1. Flight plans may be entered into the computer from remote points such as an operations office.
- 2. The clearance function is simplified through automation.
- 3. Tabular displays provide a method of automating the control transfer function.
- 4. Sector size is increased through the separation of planning and active control functions.

The use of beacon data by the data processor provides a

means of associating flight plan data with radar tracks. The radar controller will be able to handle more aircraft since he is relieved of the advance planning function which is carried out by a centralized team of planning controllers.

The flight to be described originates at a metroplex terminal and flies to another metroplex terminal located in the area of an adjacent ARTCC. The aircraft is equipped with VHF communications, VOR/DME and an identity and height reporting transponder. The metroplex terminals are fully implemented with the recommended equipment configuration and computer assistance is available for flow planning, conflict detection and resolution, terminal area traffic scheduling and vectoring of traffic in the final spacing area. This section will indicate in summary form the sequence of major events that occur during the flight.

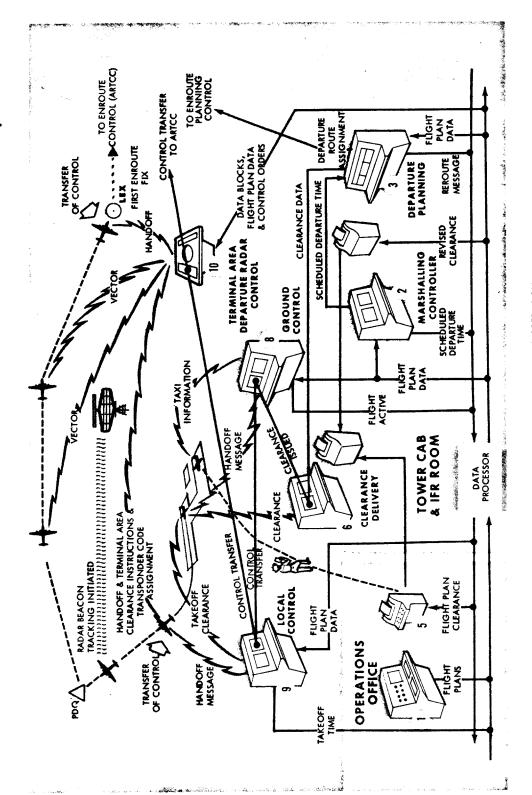


FIGURE 38 DEPARTURE TERMINAL OPERATION

Departure

Figure 38 shows the control consoles in the tower cab and terminal area control facility that will be utilized in the planning and control actions relating to this flight. In addition, the equipment shown in the lower left portion of the diagram is provided at a typical military or civil operations room to permit direct entry of the flight plan into the data processor and to print the issued clearances.

The pilot of a typical flight in the automated environment files his flight plan with an operator at a data entry device (console 1 in Figure 38) located in an operations room at the departure airport. The plan is error-checked by the computer, accepted and an acknowledgment returned to the operations room. As the departure time for the flight approaches, the appropriate data on the flight are posted on the consoles of the marshalling, departure-planning and enroute-planning controllers. At the appropriate time for the pilot to receive his clearance, the marshalling controller (console 2) assisted by the computer selects the departure time for this flight and enters it into the system. The enroute-planning controller (console 4) in the ARTCC examines the enroute portion of the flight, notes a computergenerated planning conflict indication and initiates a reroute action.

The departure planning controller (console 3) examines the terminal area departure route and posts the flight on the route board. This controller also notes the reroute action and instructs the computer to issue a clearance on the basis of the new route. The clearance with the revised route is printed out in the operations room (printer 5) for immediate delivery to the pilot. The clearance contains a transponder code assignment for the flight. A copy of the complete clearance may also be printed out on request at the departure planner's position (console 3) and at the clearance delivery or ground control position (console 6). The latter controller is thus able to issue clearances to pilots in the run-up area who were unable to obtain a printed copy from an operations room. Subsequent clearance revisions are automatically printed out at the clearance, the computer updates the displays on the flow control console (console 7 in Figure 39) in the ARTCC by adding the new flight to the future traffic.

The pilot, having received his clearance at the operations room, proceeds to the aircraft and, when ready to go, contacts the ground controller (console 8) for taxi instructions. The ground controller issues taxi information and advises the pilot of any last minute clearance changes when the pilot reaches the run-up area. The issuance of the clearance is acknowledged to the computer when the ground controller presses the proper button on the clearance delivery board (console 6). This action causes data on the flight to be posted at local control (console 9) and departure radar control (console 10). When the pilot advises that he is ready for takeoff, local control (console 9) is made aware, through his display, that the flight has its final clearance and is ready for takeoff.

At the proper time the pilot is cleared for takeoff. Local control enters the takeoff time by pressing the appropriate button on his display. Subsequently, the local controller instructs the pilot to contact departure radar control. As

soon as the aircraft is airborne the local controller executes a control transfer by pushing the control transfer button on his display. The pilot then contacts the terminal area departure controller (console 10) who gives him any additional terminal area instructions as appropriate. As soon as the data processing system starts receiving from the aircraft via the radar beacon system the discrete transponder code specified in the clearance, it initiates a radar track which is displayed with an associated alphanumeric data block on the controller's plan-view display. As shown in Figure 38 the terminal area departure radar controller

issues several vectors to the pilot to route his aircraft around other aircraft in the terminal area.

When the aircraft approaches the fix LEX the terminal area departure radar controller presses his transfer of control button which causes a message to be sent to enroute controller No. 1 (console 11). He next instructs the pilot to contact enroute controller No. 1 and gives him the frequency. After the enroute controller has established communications with the aircraft, he accepts the control transfer by pressing his transfer of control button.

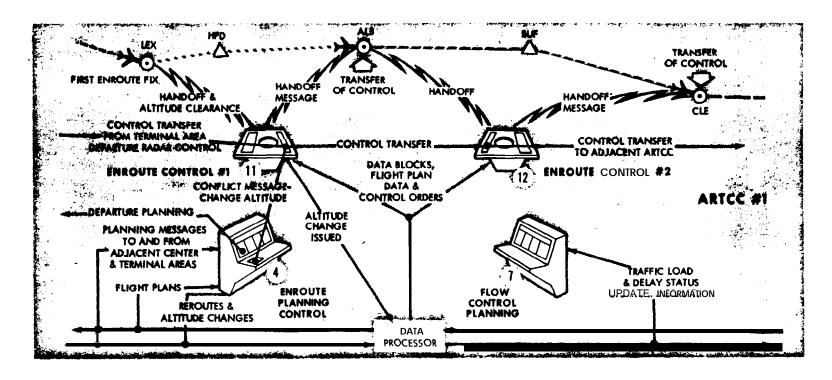


FIGURE 39 ENROUTE OPERATION

Enroute

As the flight progresses, the enroute controller gives the pilot a revision to his clearance. The revision, in this case, is a change in altitude that the planning controller (console 4) had initiated to resolve a future conflict that had been detected by the computer. The conflict resolution message was sent to the enroute controller by the planning controller through the tabular display subsystem. It should be noted that voice position reports are not required on this flight as the ground data processing subsystem obtains three-

dimensional position information from the radar beacon subsystem. The only voice communications required are those involving actual control messages or other essential information. The most frequent examples include transfer of control and change of altitude messages.

As the aircraft approaches the fix ALB, enroute controller No. 1 (console 11) executes a control transfer to enroute controller No. 2 (console 12). Similarly, enroute controller No. 2 later executes a control transfer to enroute controller No. 3 (console 15 in Figure 40).

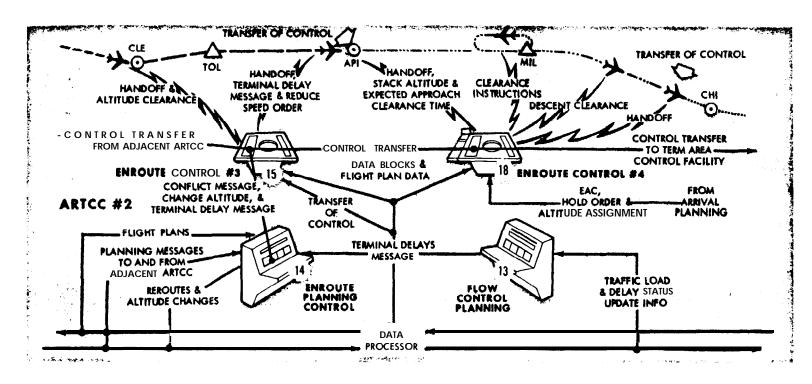


FIGURE 4.0 ENROUTE OPERATION (Continued)

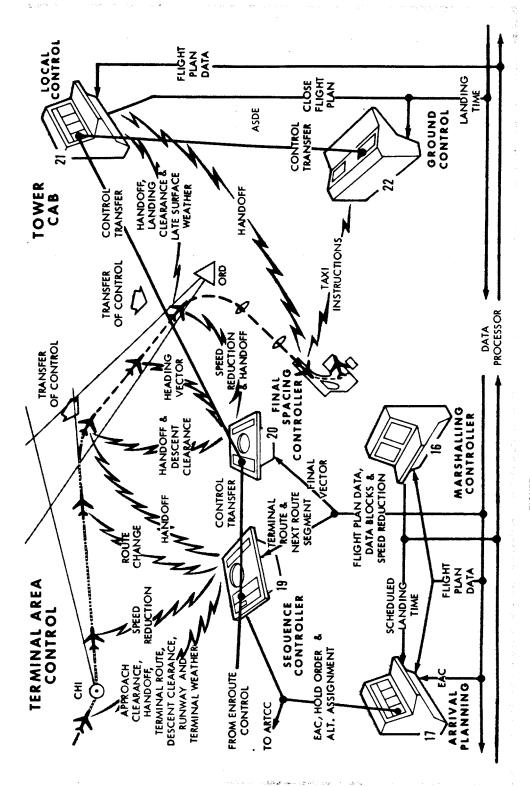


FIGURE 41 ARRIVAL TERMINAL OPERATION

The enroute planning controller (console 14) in the second ARTCC assisted by the enroute computer had detected and resolved a predicted future conflict for this flight prior to its entry into the area. The conflid situation was not urgent enough to require issuance of the clearances revision by the previous center. The required control action had been sent to enroute controller No. 3 (console 15) who issues the clearance revision to the pilot at the time the latter enters his sector. As the flight proceeds toward API. the flow control planner (console 13) notes that terminal area delays at the destination airport for this flight are increasing. He issues a terminal area delay message to the enroute planning controller (console 14) who institutes a speed reduction order and transmits this to enroute controller No. 3. The latter issues the enroute speed reduction order and terminal area delay message to the pilot. Shortly thereafter enroute controller No. 3 executes a control transfer to enroute controller No. 4 (console 18).

Arrival

During the time that the flight was proceeding from TOL to API, data on the flight was posted in the destination metroplex terminal area control facility at the marshalling controller (console 16 in Figure 41) and arrival planning controller (console 17) consoles. The marshalling controller assigned a scheduled landing time based on the computer calculation made prior to speed reduction. The scheduled landing time is used by the computer to generate a hold order and expected approach clearance time (EAC) for the flight. This information was posted on the arrival planning board (console 17).

The planning controller. (console 1'7) noted that a hold was necessary for the flight and assigned an altitude at the holding fix MIL. The assigned altitude, EAC and hold order for the flight which appeared on the MIL holding stack board on the planning console, also appeared on the MIL repeater boards of enroute control No. 4 (console 18) and the sequence control (console 19).

When enroute control No. 4 accepts the control transfer, the controller issues the clearance revision giving the pilot the holding stack altitude and EAC. The pilot remains in the holding pattern until the controller, prompted by a computer-generated call-out signal presented on his display, issues further clearance to the pilot. This includes clearing the aircraft to descend to an entrance altitude for the terminal area. He next executes a control transfer to the sequence controller (console 19). It should be noted that when the entry fix is used as the holding fix to absorb delay in excess of that possible through early speed reductions or flight path adjustment, the entry fix and holding stack are under the jurisdiction of the sequence controller.

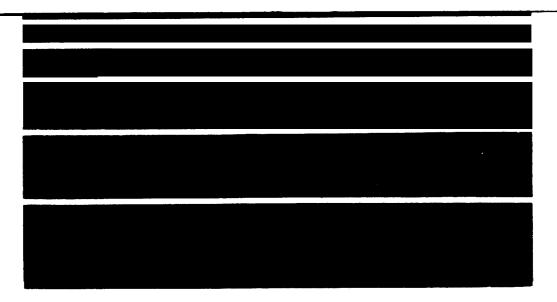
The data processor selects the proper terminal area route and posts it on the sequence controller's display. When the sequence controller accepts the control transfer, he issues the approach clearance including terminal VOR route, runway number, terminal weather and descent instructions to the pilot. As the flight progresses along the VOR radial, the computer monitors the progress of the aircraft and indicates to the controller through his display the time at which the aircraft should reduce to an intermediate speed configuration. Still later, based on flight progress, the computer selects and posts any modifications to subsequent

terminal area VOR route segments. The sequence controller issues these instructions by voice communication with the pilot and then indicates to the computer by activating a pushbutton on his display that the control instructions have been issued.

When the aircraft is approximately 20 to 25 miles from touchdown, the sequence controller transfers control of the aircraft to the final spacing controller (console 20). The final spacing controller, in this case, issues appropriate control instructions involving descent to final approach altitude, assumption of specified heading vectors for final time adjustment and reduction to final approach speed. After the pilot has turned on final approach and reduced to final approach speed, the final spacing controller executes a control transfer to local control (console 21).

Local control clears the flight to land and issues present surface weather information to the pilot. After the aircraft, has landed and turned off the runway, the local controller executes a control transfer to the ground controller (console 22) who issues taxi instructions. The local controller activabs a pushbutton in the appropriate line of data on his display at the time of landing to inform the data processor of this time. This action also automatically closes the pilot's flight plan.

This concludes the summary of the handling of a flight in the highest density traffic areas that will exist in the automated environment. There are relatively few metroplex terminals and in less dense terminal areas some functions, such as terminal area sequencing, will still be performed manually.



Portions of the airspace utilization system will be installed in the field prior to the time when the complete ATC subsystem has been developed, tested and fully evaluated. This approach requires the establishment of well-defined intermediate goals and prescribes an implementation program of an evolutionary nature to permit a gradual buildup marked by an increasing degree of sophistication and capability. For this purpose, an automation ladder of eight steps introduces an ideal procedure for progressive implementation of the ATC subsystem. The order of events in this idealized ladder would be followed if the specific hardware could be made available in the proper time sequence.

Since digital computers exist now, early implementation of the data processing portion of the system is possible even though the available machines may not be optimum in every respect. The problem in achieving the optimum sequence defined in the automat,ion 'ladder is not in developing a data processor, but rather in providing a truly satisfactory man-machine interface or specifically to provide the proper displays and controller-computer intercommunication devices. Since the displays that are available are not in all cases satisfactory, the desired equipment must be evolved through further development. The progressive implementation plan that follows, not only considers the logical sequence in which equipment groups must, be installed, but

also takes into account the times at which the necessary equipment will become available as a result, of the development program.

The progressive implementation plan takes account of the fact that some operational sites will require only an improved display capability and no data processing capability. This subsystem is shown in Figure 42 and described on page 67. Further, the plan was developed recognizing that the installation of a radar inputs processor in a given data processing location will be determined partly on the basis of technical need and partly on the basis of the relative cost/benefit that its installation will afford. The system can operate without the radar inputs processor; however? the controller must then manually enter position reports on each flight at periodic intervals. In consideration of these practical matters, the automation ladder has been adjusted in order to formulate a realistic plan for progressive implementation.

Automation Ladder

An automation ladder that may be used as a guide in establishing the progressive implementation stages has the following levels of system capability:

- 1. Completely manual control system including communications with or without radar.
- 2. Largely manual system, but a data processor has been introduced to carry out. some specific tasks, such as:
 - a. Flight plan processing and ETA computation.

b. Flight plan updating.

In this step the man checks the machine-prepared information, but the machine performs only limited service for the man.

- 3. The manual system of control continues; however, the controller is now provided with limited alphanumeric information derived from the beacon decoder system on the CRT displays.
- 4. The data processor and radar display system are interconnected so that extrapolated flight plan tracks may be displayed on the CRT displays with limited flight plan data. Joystick inputs of aircraft position are used to update the flight plan position. Electronic tabular displays of flight plan data are added in this step to assist the controller in carrying out the planning function.
- 5. Primary radar and radar beacon tracking capability is provided so that extrapolated flight plan data may be associated with the selected radar target. The tracking capability will reduce controller workload by automatically providing the data processor with aircraft position information and by maintaining the identity of all the targets corresponding to controlled aircraft.. In sectors where radar coverage does not exist, the CRT display will present extrapolated flight plan tracks which can be updated periodically by joystick-manipulated position entries based on pilot-position reports.
- 6. A computer evaluation process is introduced to permit

the data processing and display subsystem to detect and post a forced display covering a situation of a routine or potentially dangerous nature which requires controller action. Representative situations include:

- a. Transfer of control pending.
- b. Future conflict situation detected (advance planning).
- c. Present conflict situation detected (active control). Step 6 initiates a level of capability which permits the data processing system to check the man and to call situations requiring control action to his attention.
- 7. The computer is programmed to assist, the controller in the decision-making process to the extent that it would recommend solutions to the problems that it has detected. These solutions would be in the form of specific control actions that could be taken and represent valid solutions to the problems. The computer would, for example:
 - a. Recommend route and/or altitude changes to assist. the planning controller in reducing the incidence rate of future conflict, situations. This would permit expansion of sector boundaries by increasing the number of aircraft that a controller could safely handle.
 - b. Select aircraft climb/descent profiles and post these on the displays as part of the plan.
 - c. Sequence and resequence aircraft entering metroplex terminals and generate control orders to achieve the sequence.
 - d. Recommend solutions for conflict situations.

8. The computer is programmed to institute flow control on a center and later nationwide basis. Here the computer is employed to assess future traffic flow and density by sectors and to provide the capability necessary to institute flow control planning on a centralized basis within the center. Traffic densities that could overload sectors are predicted and the planning controller institutes rerouting of traffic or reconfiguration of sectors to limit the traffic under any controller's jurisdiction to a number that, can be handled with safety.

The present ATC subsystem is a step 1 and step 2 subsystem as computers have been introduced into some operational environments to do flight plan processing, ETA computation and preparation of printed flight strips. Examination of the overall system goals, state-of-the-art and predicted traffic load, indicates fairly clearly that the system in operational use in 1975 must. provide the functions delineated in steps 1 through 6 above. To the extent possible and consistent with cost/benefit analysis, the functions of steps '7 and 8 will be implemented. These latter functions can largely be achieved by progressive expansion of the data processor capability.

The controller will retain the responsibility for the selection and issuance of all control orders whether proposed solutions are generated by the data processor or not. He will be assisted by the data processor through computergenerated information in carrying out some of the ATC functions noted above.

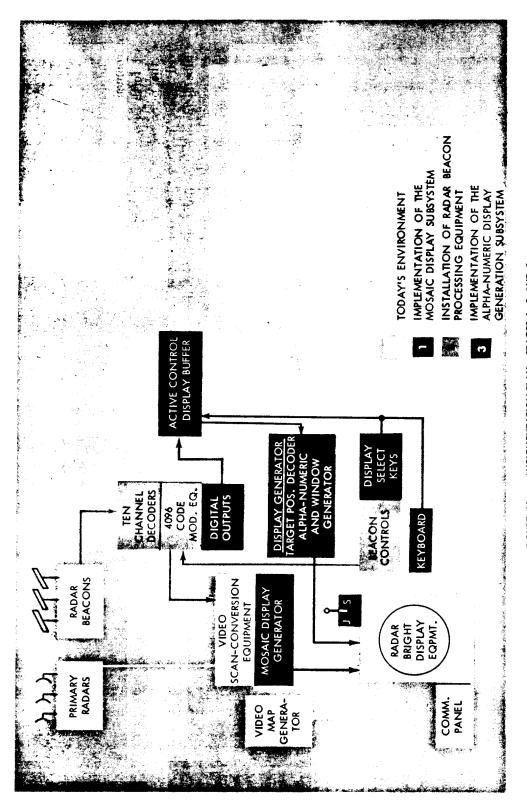


FIGURE 42 IMPLEMENTATION PLAN-STAGES 1, 2 AND 3

Progressive Implementation Plan

The implementation plan for installation of the display subsystem components consists of six equipment installation stages which may be carried out sequentially. The first improvements to be instituted in the operational environment are associated with implementation of step 3 as set forth in the automation ladder. This step has as a goal the provision of limited alphanumeric information, derived from the beacon decoder system, on the cathode ray tube displays. It includes modification of the existing beacon decoding equipment, addition of circuitry to radar scan conversion equipment to generate mosaic displays and installation of alphanumeric storage and character generation equipment.

Implementation of the Mosaic Display Subsystem Primary radar and radar beacon video scan conversion and radar bright display equipments will be modified to include the sync phasing and blanking circuitry required to generate mosaic displays. The joystick video marker which forms a part of the mosaic display subsystem will also be installed. The equipment installed in this stage is shown in red in Figure 42.

Installation of Radar Beacon Processing Equipment Radar beacon processing equipment of the ten channel decoder type will be installed along with modification kits that will provide a decoding capability for 4096 identity codes, altitude decoding and conversion of transponder height data to mean sea level altitude where applicable; and digital readout of beacon code altitude and plan position coordinates for display generation. Single code decoders in present operational use will be replaced with modified ten channel decoders. The equipment installed in this stage is shown in light red in Figure 42.

Implementation of the Alphanumeric Display Generation Subsystem

The controller displays will be modified to incorporate the off-centering and scale-expansion controls associated with the radar mosaic display subsystem. In addition, the active control display buffer and the display generator will be added at this stage. A keyboard, associated with the active control display buffer, will permit aircraft identities to be associated with specific beacon codes so that flight identity and beacon altitude can be displayed adjacent to beacon target locations. The implementation of the changes and additions presented above to the present operational environment will provide the alphanumeric generation and display capability required by the following steps in the automation ladder. The display system equipment, installed in this stage is shown in black in Figure 42.

The controller at the end of stage three will be provided with a limited alphanumeric display on beacon targets and a video handoff marker subsystem which will provide positive identification of the radar target representing the aircraft being handed off. Progress toward reducing display clutter has been achieved as the beacon video treed not be displayed along with the data blocks.

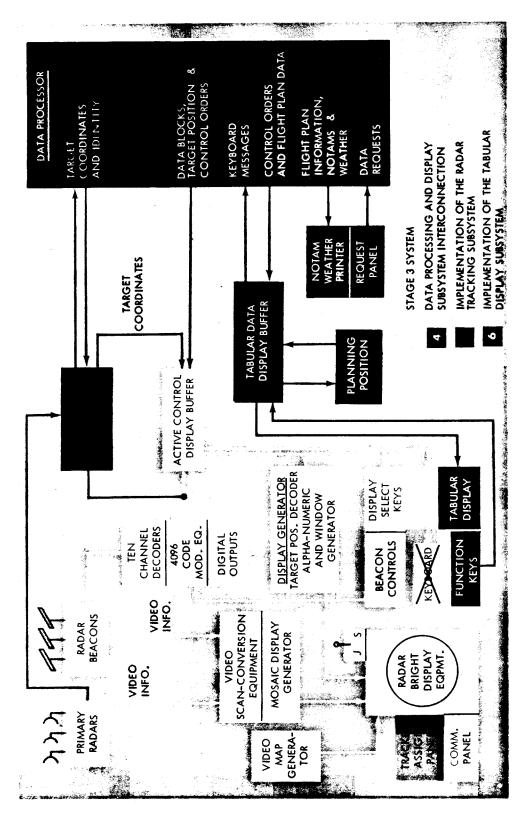


FIGURE 43 IMPLEMENTATION PLAN-STAGES 4, 5 AND 6

4 Data Processing and Display Subsystem Inferconnection

Once the active control display buffer and associated equipment are installed, the active control display subsystem will be interconnected with the computer so that computer extrapolated flight plan position and alphanumeric data can be displayed for all controlled aircraft on the cathoderay tube displays. At this time association of radar returns with flight plan data on those aircraft in radar coverage will be done manually using the joystick technique. The computer will provide the "windows" at this stage to aid in cleaning up the display. Hard copy printers will be installed to provide printouts of flight plan and weather data on demand and NOTAM data automatically. The additiuns to the ATC subsystem in this stage are shown in red in Figure 43.

Implementation of the Radar Cocking Subsystem The addition of radar tracking equipment to the computer subsystem will relieve the controller of the workload of maintaining target identity through manual tracking techniques, after the controller has made the initial identification of primary radar targets representing aircraft not equipped with transponders. In high altitude radar positive control sectors, where all aircraft are equipped with beacon transponders, all radar video can be removed from the display to complete the display "clean up" process. Display generation in the high altitude sectors can be done on the basis of presenting synthetic plan view displays to the controllers. Figure 43 shows the additions to the ATC subsystem in this phase of implementation in light red.

6 implementation of the Tabular Display Subsystem The last portion of the display subsystem to be operationally implemented is the tabular display equipment. This results from the necessity of conducting some development efforts to obtain the optimum tabular display and from the fact that the automated tabular display equipment represents a completely new subsystem for the operational sites.

The tabular display subsystem will include the central tabular data display buffer, the flow control and planning consoles and the tabular displays located at each active control position. This stage will also include the computer interconnection, the interconnection of the joystick reporting system with the tabular message generation system, the installation of remoting equipment to transmit tabular display data to remote tower cabs and IFR rooms and the removal of flight progress boards. The implementation of the tabular displays will include computer assistance in the planning function. Figure 43 shows the added equipment in black.

Installation of the tabular displays will complete the installation of the ATC subsystem and the system capability will now have reached the sixth step of the automation ladder. The full six-stage implementation of the system will be provided at the ARTCC facilities existing in 1970 and at 10 or 15 major terminal area control facilities. Many of the additional 200 terminal facilities that will have radar inputs, but which do not require a data processor, will be equipped with the system configuration shown in Figure 42. This will give them the capability defined as step three of the automation ladder.

Time Schedule

A program schedule for developing the ATC subsystem for implementation in the operational environment will follow the six progressive implementation stages and the time schedule shown below. This schedule will result in the development, procurement and installation of a breadboard system at research and development test facilities by January 1, 1964. Although this system will have breadboard display equipment closely resembling the final units, the data processing and radar inputs processing functions will be carried out by data processing equipment existing at these facilities. At the conclusion of the first test cycle, the installation at operational facilities will be undertaken for the equipment in stages 1,2 and 3.

The first test cycle will also provide the information necessary to determine the size and capabilities of the computer and radar inputs processor equipment. Specifications will be written near the end of the first test cycle for the procurement of prototype equipment. This equipment, utilizing programs (modified as necessary) from the test site computers, will be procured and installed at the research and development test facility in preparation for the second test cycle. Specifications for the procurement of the computer, tracking equipment and tabular displays will be prepared as the result of the evaluation of the prototypes used in the second test cycle. At the completion of the second test cycle, field implement&ion can be initiated for the equipment in stages 4, 5 and 6.

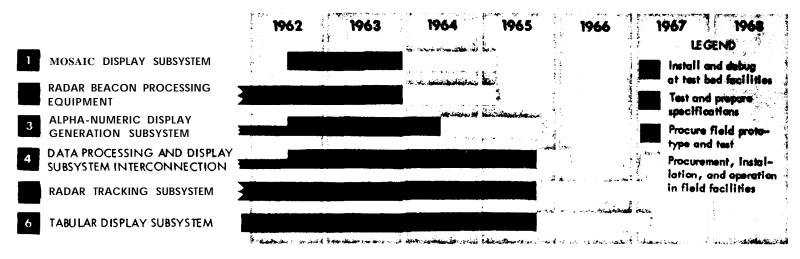


FIGURE 44 PROGRESSIVE IMPLEMENTATION PLAN FOR THE ATC SUBSYSTEM